

R. H. [unclear]
SAF / *PMO*

PHO-TR409
REVISION A

PROGRAM REQUIREMENTS FOR THE DRAFT II SYSTEM

CONTRACT NAS 9-1261

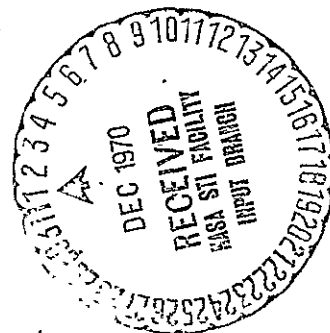
25 SEPTEMBER 1970

1
Approved for Release by NSA on 09-11-2013 pursuant to E.O. 13526

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

PHILCO 
Philco-Ford Corporation



N71-11326

FACILITY FORM 602

(ACCESSION NUMBER)

132

(PAGES)

CR-108662

(NASA CR OR TMX OR AD NUMBER)

(THRU)

G3

(CODE)

08

(CATEGORY)

Reproduced by
**NATIONAL TECHNICAL
INFORMATION SERVICE**
Springfield, Va. 22151

CR-108662

PHO-TR409
Revision A
25 September 1970

PROGRAM REQUIREMENTS
FOR THE DRAFT II SYSTEM

Contract NAS 9-1261

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

Prepared by: R. L. Runnels
J. Carlos Alvarez (Appendices A and D)

Approved by:

N. M. Hines

N. M. Hines, Manager
Support Engineering Department

G. Straty

G. Straty, Manager
System Engineering Activity

PHILCO-FORD CORPORATION
AEROSPACE AND DEFENSE SYSTEMS OPERATIONS
WDL DIVISION
HOUSTON OPERATION
1002 GEMINI AVENUE
HOUSTON, TEXAS

FOREWORD

This document was prepared by Philco Houston Operations under Part III of Exhibit A, Statement of Work, to Modification No. 80 to Contract NAS 9-1261.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION	
1.1	General	1-1
1.2	Scope	1-2
1.3	Applicable References	1-3
1.4	Notes	1-4
2	ORGANIZATIONAL INTERFACES	
2.1	General	2-1
2.2	Display Design and Production Interface	2-1
2.3	Users of DRAFT II End Items	2-2
2.4	Functional Flow	2-2
3	CONSOLE OPERATION	
3.1	General	3-1
3.2	Monitors	3-1
3.3	Pointer	3-1
3.4	Action Switch	3-3
3.5	Keyboard	3-3
3.6	Hardcopier	3-3
3.7	System Response Times	3-3
3.8	Auxiliary Functions	3-4
4	DRAFT DATA BASE	
4.1	General	4-1
4.2	Display Library "Table of Contents"	4-1
4.2.1	Manual Select Keyboard (MSK)	4-1
4.2.2	Format Control Number (FCN)	4-1
4.2.3	Program Change Letter (PCL)	4-2
4.2.4	Status Letter	4-2
4.2.5	Display TYPE	4-2
4.2.6	Mission Number	4-2

TABLE OF CONTENTS (CONT'D)

<u>Section</u>		<u>Page</u>
4.3	Display Library	4-3
4.3.1	Header Information	4-3
4.3.2	Static Data Alphanumerics	4-4
4.3.3	Static Data Lines (Vectors)	4-5
4.3.4	Dynamic Data Alphanumerics (D. Data)	4-5
4.3.5	Format Description Sheet (FDS)	4-5
4.4	DTE Diskpack Tables	4-9
4.5	Entity Library	4-9
4.5.1	Entity TOC	4-9
4.5.2	Entity Static Data	4-9
4.5.3	Entity Dynamic Data	4-10
5	PROGRAM OPERATIONAL DESCRIPTION	
5.1	General	5-1
5.1.1	System Initialization and Termination	5-1
5.1.2	Cursor Symbols	5-1
5.1.3	Cursor Homing	5-3
5.1.4	Selection Tracks	5-5
5.1.5	DM Tags	5-5
5.1.6	Pointing	5-5
5.1.7	Keyboard Functions	5-6
5.1.8	IM Permanent Displays	5-11
5.1.9	IM Secondary Displays	5-12
5.1.10	Error Messages and Error Recovery	5-12
5.2	DESIGN DISPLAY	5-13
5.2.1	Alpha/Dynamic Data	5-13
5.2.2	Line/Ellipse	5-20
5.2.3	Graphs	5-24
5.2.4	Curves	5-28
5.2.5	Entities	5-35

TABLE OF CONTENTS (CONT'D)

<u>Section</u>		<u>Page</u>
5.3	SAVE DISPLAY	5-41
5.4	CALL DISPLAY	5-47
5.5	OUTPUT EXTERNAL	5-51
5.5.1	TOC Lists	5-51
5.5.2	FDS Lists	5-51
5.5.3	Gerber Language Tape	5-53
5.5.4	RTCC Background Tape	5-53
5.5.5	FDS Tape	5-54
5.5.6	DTE Mission Diskpack	5-54
5.5.7	Selected MD Listings	5-54
5.6	DELETE DISPLAY	5-55
5.7	DM ERASE	5-55
5.8	INPUT EXTERNAL	5-55
5.8.1	Display Library Input	5-55
5.8.2	DTE Diagnostic Routines	5-57
5.8.3	Character Font Table	5-57
5.8.4	Coordinate Conversion Table	5-57

<u>Appendix</u>		<u>Page</u>
A	SURVEY OF APPLICABLE SMOOTH CURVE FAIRING TECHNIQUES	
A.1	General	A-1
A.2	Mechanical Drawing Techniques	A-1
A.3	Interpolation Methods	A-3
A.4	Curve Fitting	A-21
A.5	Bibliography	A-31
B	NEAREST CHARACTER BOX COORDINATES	B-1
C	EXTERNAL INPUT FORMATS AND CODES	
C.1	Symbolic Word Formats	C-1
C.2	DTE/DRAFT II Symbol Library Codes	C-3
D	CONSTRUCTION OF ELLIPSES (CIRCLES)	D-1
E	DRAFT KEYBOARD FUNCTION CODES	E-1

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2-1	DRAFT II System Organizational Interfaces	2-3
3-1	DRAFT II System Flow	3-2
5-1	Major Decision Matrix	5-2
5-2	Pointer Cursor on the 7 x 9 Character Dot Matrix	5-4
5-3	Display Design Matrix	5-14
5-4	CONSTRUCT ALPHA/DYNAM	5-15
5-5	Alpha FDS Display	5-17
5-6	CONSTRUCT LINE/ELLIPSE	5-21
5-7	CONSTRUCT GRAPH	5-25
5-8	Plot FDS	5-26
5-9	CONSTRUCT CURVE	5-29
5-10	MODIFY CURVE	5-30
5-11	Curve Data Display	5-32
5-12	CALL ENTITY	5-38
5-13	Entity TOC Display	5-39
5-14	SAVE DISPLAY	5-42
5-15	TOC and Header Display	5-43
5-16	Overlay Message Display	5-44
5-17	Deletion Authority Message	5-46
5-18	CALL DISPLAY	5-48
5-19	TOC Entry Block	5-49
5-20	TOC Display	5-50
5-21	Output External Display	5-52
5-22	External Input Display	5-56

LIST OF TABLES

<u>Table</u>		<u>Page</u>
5-1	Keyboard Functions	5-7
A-1	Partial Derivatives for Sum of Residual Squares for a Conic Defining Equation	A-24
B-1	Character Size Constant Table	B-1

SECTION 1

INTRODUCTION

1.1 GENERAL

The DRAFT system consists of a computer-driven digital display system, two operator consoles, a high-speed computer, a console to computer interface, a TV monitor hardcopy device, and the associated DRAFT software. Each console contains two display monitors, a pointer device, a typewriter and function keyboard, and an auxiliary function panel.

Since DRAFT is interactive, the operator is able to create a display in the medium in which it is to be used, i.e., the television display monitor. Its purpose is to design and document display formats to be used in a large computer driven real-time display system such as the NASA/MSC Mission Control Center. The large amount of required data to be displayed in the MCC necessitates a variety of display formats ranging from plots to tables.

Design of a display format requires the capability to organize data in logical and instantly recognizable form. Groups of data within a display may require dozens of trial combinations before the best arrangement is achieved.

A display format typically consists of two types of data: static and dynamic. Static data is unchanged during the life of a display and provides the background against which the real-time data is displayed. Dynamic data changes in real-time and represents some remote event or measurement variation. The combination of static and dynamic data constitutes a complete display.

The documentation of a display format may be divided into two basic areas. The first area specifies the location and exact content of the static or background data. The Display Specification Hardcopy (DSH) provides this documentation. The second area specifies the location and visual configuration of the dynamic data as well as the source, content, and requirements for programming. The Format Description Sheet (FDS) documents this data.

Working outputs from DRAFT include both listings and tapes. "Table of Contents" (TOC) listings provide information for production, control and scheduling and selected listings from the Mission Diskpack provide for validation checking of the program output. A digital background output tape provides an input for the SCORE checkout program and for RTCC background generation, and an FDS tape provides an input for report generation and dynamic data generation.

In addition to design, documentation and working listings, the DRAFT system produces a static data background diskpack for the DTE display system and a numerical control tape for drafting the D/TV display system background slides. Both types of background, digital and film, are used in the MCC.

1.2 SCOPE

Described within this document are the program requirements for the Display Retrieval and Formatting Technique (DRAFT). This introductory section tells the purpose of the system, lists references, and notes additions and changes to the original version. The section on organizational interfaces outlines the operational environment of the system, its work flow and its end items. The console operations section briefly describes the hardware through which the operator interacts with the system software and the section on the DRAFT data base describes the type of information entered and stored by the operators. The section on program operation contains the operators actions and required computer program responses. The appendices supply information not available in the documents listed with the references.

1.3 APPLICABLE REFERENCES

- A. *Display Formats Manual*, PHO-TR147, Revision C, Change 3.
- B. *DTE Background Disk Recording Program Requirements*, PHO-TR446.
- C. *Digital Television Equipment Procurement Specification*, SP-08873A.
- D. *DRAFT Display/Control System Performance Specification*, SE-09467.
- E. Gerber Publication Series 1000 Input Format and Code Instructions, Gerber Scientific Company, Hartford, Connecticut.
- F. NASA MSC Memorandum Ref. Number 70-FS-25-12, Format for DTE Display Background Tape.

1.4 NOTES

Differences exist between the DTDS/360/44 program and the requirements outlined in this document. These are due to functional hardware differences and the desire to improve on the DRAFT system. In some cases, a slightly different operations sequence or series of feedback messages has been specified. In other cases, limitations of the 360/44 system have required additional operator decisions not spelled out in this document.

Items known to be significant differences or additions are flagged and refer to the following numbered paragraphs:

- ① The operator and date identifications are not included in the 360/44 program.
- ② Stored homing for entities is not available in the 360/44 program.
- ③ The DRAFT II 360/44 initialization procedure is unique to the DTDS. Backup record capabilities are provided off line.
- ④ The character box homing function in the 360/44 program operates only for size two characters. Homing for all other character sizes is performed either by pointing (coordinate homing) or by typing in the coordinates (ANK homing). The sequence of homing operations is also different on the 360/44.
- ⑤ The DTDS hardware and 360/44 program do not include the following keyboard functions: The subscript key ($\frac{1}{2}\downarrow$), the superscript key ($\frac{1}{2}\uparrow$), the character space (CS) key, the insert key (INS), the increment (INC) key and the delete (DEL) key. Also, entry of character sizes one through six is not a discrete function related to a keyboard entry in the 360/44 program.
- ⑥ The structure of the DRAFT II 360/44 word formats and logic provides that no data will be lost when attempting to move portions of an entity or group outside the 1024 x 1024 display area. No error message is provided, however, and the operator must recognize visually the occurrence of "wrap-around."

- ⑦ Only ANK and COORDINATE homing are operational in the MOVE and COPY modes on the 360/44.
- ⑧ The DRAFT II 360/44 program presents DM tags 25 at a time. Provision is made for paging to succeeding sets of 25 by pointing to MORE SELECTIONS on the IM. Paging is terminated by selecting EXIT THIS MODE on IM.
- ⑨ Only the zero/zero divisions option is implemented on the 360/44. The entry of zeros for DIVISIONS bypasses the automatic construction routines permitting manual construction of graphs.
- ⑩ The 360/44 program does not provide for paging backward of the ENTITY TOC.
- ⑪ The 360/44 system does not call the display prior to deletion. Call must be selected first.
- ⑫ The 360/44 display system does not provide a CRT TOC. A message IDENTIFY THE DESIRED DISPLAY (ID NO.) is added to the IM, and displays are called by an ID number obtained from a TOC printer listing.
- ⑬ This output is created off line in the 360/44 system.
- ⑭ This input is accomplished off line in the 360/44 system.

SECTION 2

ORGANIZATIONAL INTERFACES

2.1 GENERAL

There are two NASA/MSC divisions and two NASA contractors directly involved in the development and use of digital displays. Flight Control Division determines what displays are needed and is the ultimate user during manned spaceflight missions. Flight Support Division, Flight Software Branch supplies computer programming support. IBM programs the mission operations computers which operate the display control system. Philco-Ford Corporation provides the background slides and digital background disk records and documentation for each display. The required close liaison and cooperation between each of these groups during display design development and specification is provided primarily by the Philco-Ford display formats engineer.

2.2 DISPLAY DESIGN AND PRODUCTION INTERFACE

The Philco-Ford Display Development Unit interfaces with the following organizations:

- Flight Control Division to obtain input sketches and tabular data to be organized into a display
- Flight Support Division, Flight Software Branch, to obtain mission programming data and coordinate approval of displays for mission use
- Lunar and Earth Sciences Division, Mapping Sciences Branch, for use of the Gerber plotter for background slide artwork production
- Lockheed Electronics Company to schedule actual use and operation of the Gerber plotter
- NASA Flight Operations Support Office to schedule use of the 360/75 computer.

2.3 USERS OF DRAFT II END ITEMS

The following organizations use the indicated DRAFT II system end items for support of the display control system operation.

- A. IBM uses the RTCC Background Tape for report generation and program checkout.
- B. IBM uses the Display Specification Hardcopy (DSH) and Format Description Sheet (FDS) tape in programming displays. A listing of the FDS file is also provided.
- C. Philco-Ford uses a copy of the DSH and the FDS printout for reproduction and publication in the applicable technical reports.
- D. Philco-Ford uses the Gerber Language Tape (GLT) in producing the artwork to be photo-reduced to background slide size.
- E. Philco-Ford and NASA use "Table of Contents" (TOC) listings for schedule monitoring and control.
- F. Philco-Ford utilizes DRK listings in the development and production of DRK reticles used in the MCC.
- G. Philco-Ford utilizes listings of the DTE Diskpack, such as MSK-to-TRACK conversion tables during DTE system checkout.
- H. NASA uses the background slides produced for the D/TV display system and the Mission Diskpack for the DTE display system.

2.4 FUNCTIONAL FLOW

Figure 2-1 diagrams the operational steps and organizational interfaces occurring during the design, development and specification of displays with the DRAFT II system. The circled letters in Figure 2-1 identify the boxes with the following lettered paragraphs.

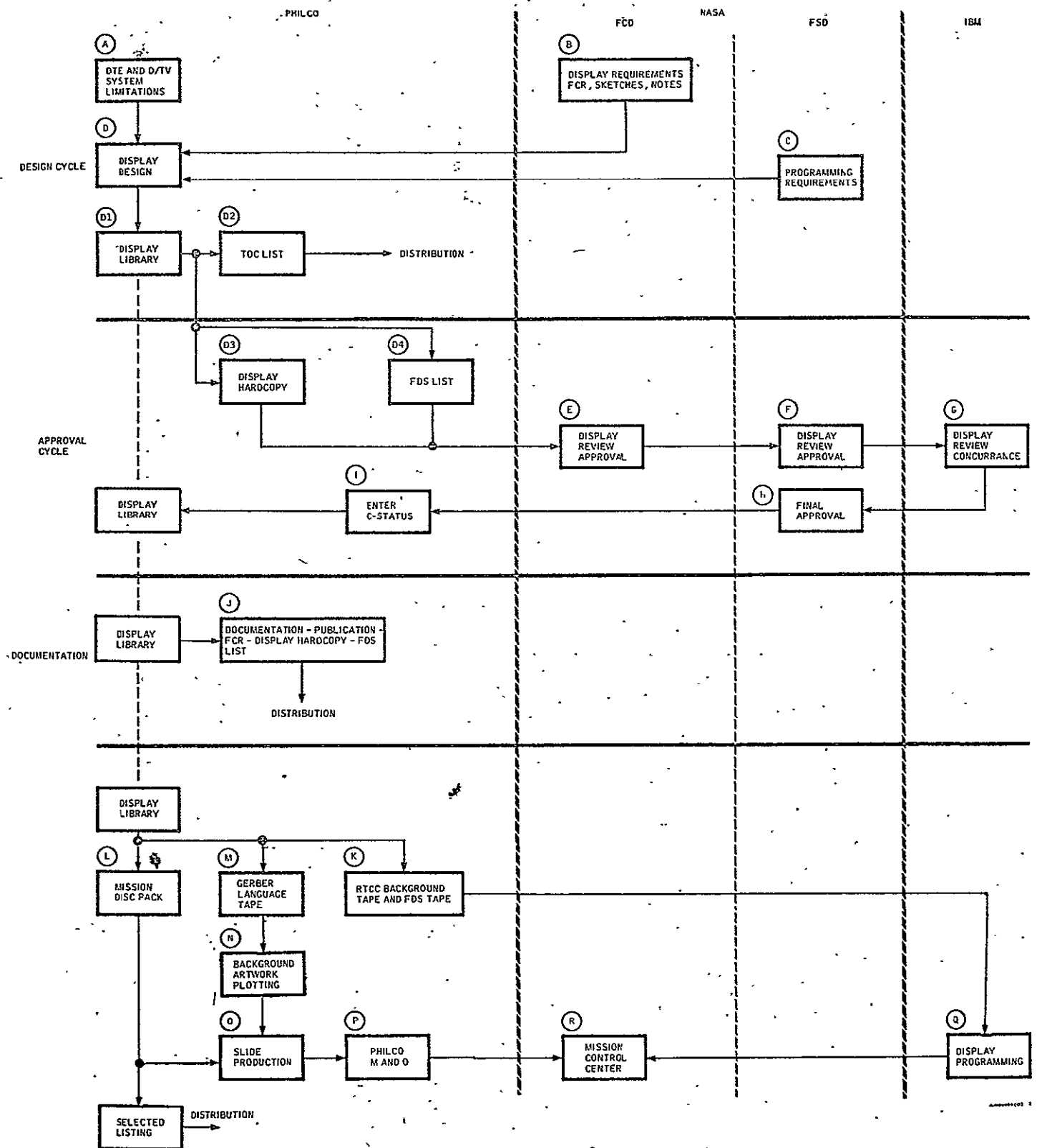


Figure 2-1 DRAFT II System Organizational Interfaces

- A. The D/TV and DTE display control systems have certain inherent characteristics which must be considered during display specification and design. Some of these are character size, number of alphanumeric characters per line, number of alphanumeric lines per page, and spacing.
- B. The request for a new or changed display is made on a Format Change Request (FCR) sheet and forwarded to the Philco-Ford Display Development Unit. The flight controller requesting a display furnishes the display design engineer with notes, sketches, and other technical data needed for the display.
- C. The Flight Software Programming Specifications provide all data on overall programming requirements and limitations.
- D. Using DRAFT II, the display design engineer produces a display in accordance with the above inputs. The following events occur:
 - 1. During design of the display, a permanent record, the digital display library (DDL), is created which contains the complete display (static and dynamic data) plus the additional data needed for programming the display.
 - 2. TOC listings are obtained and distributed for control and monitoring purposes.
 - 3. A DSH of the display screen is produced which shows both static and dynamic data location.
 - 4. A printer listing of the FDS is made.
- E. The flight controller reviews the DSH and FDS and signs the FCR indicating approval. If he wishes, he may view the display on the DRAFT II console.
- F. The cognizant Flight Software Branch engineer reviews the DSH and the FDS to assure their agreement with program requirements.

- G. The hardcopy and printout are forwarded by the Flight Software Branch technical monitor to IBM for their concurrence.
- H. After all concurrence signatures are obtained on the FCR, the Flight Software Branch approves the display for production.
- I. The display engineer enters a "C" for completed in the TOC status area after final approval.
- J. The display format specification consists of the approved FCR, FDS, and DSH. It is approved by the Philco-Ford Display Development Unit supervisor and distribution is made in the appropriate technical reports.
- K. The digital background data to be used by IBM is placed on the RTCC Background Tape in the DTE 36-bit or 48-bit word format and transmitted to IBM. The FDS tape is forwarded to IBM providing final change and update information for the display programming.
- L. The digital background data for the DTE system is extracted by DRAFT II from the DDL and placed on the Mission Diskpack.
- M. Background data is converted to Gerber language and output on a Gerber Language Tape (GLT) for use on the Gerber plotter in producing background slide artwork.
- N. The GLT is read and plotted by the Gerber 1032 automatic drafting machine to produce the artwork for the background slides.
- O. The background slide artwork is reduced and reproduced in quantities for use in the converter slide files of the D/TV display system. Slide delivery is correlated with Mission Diskpack content.
- P. Philco-Ford M&O personnel load the slides in the D/TV display system and the Mission Diskpack digital backgrounds in the DTE display system.
- Q. Using the RTCC Background and FDS tapes, IBM accomplishes the display system programming.
- R. The prime user of the display in the MCC is the Flight Control Division.

SECTION 3

CONSOLE OPERATION

3.1 GENERAL.

The DRAFT console provides for operator inputs and program interaction in designing display formats. Figure 3-1 illustrates the action and feedback loop of the DRAFT system as well as the basic output capabilities. The following paragraphs outline the functional capabilities of the console and system as used by the DRAFT operator. A capability for two identical consoles operating simultaneously is required.

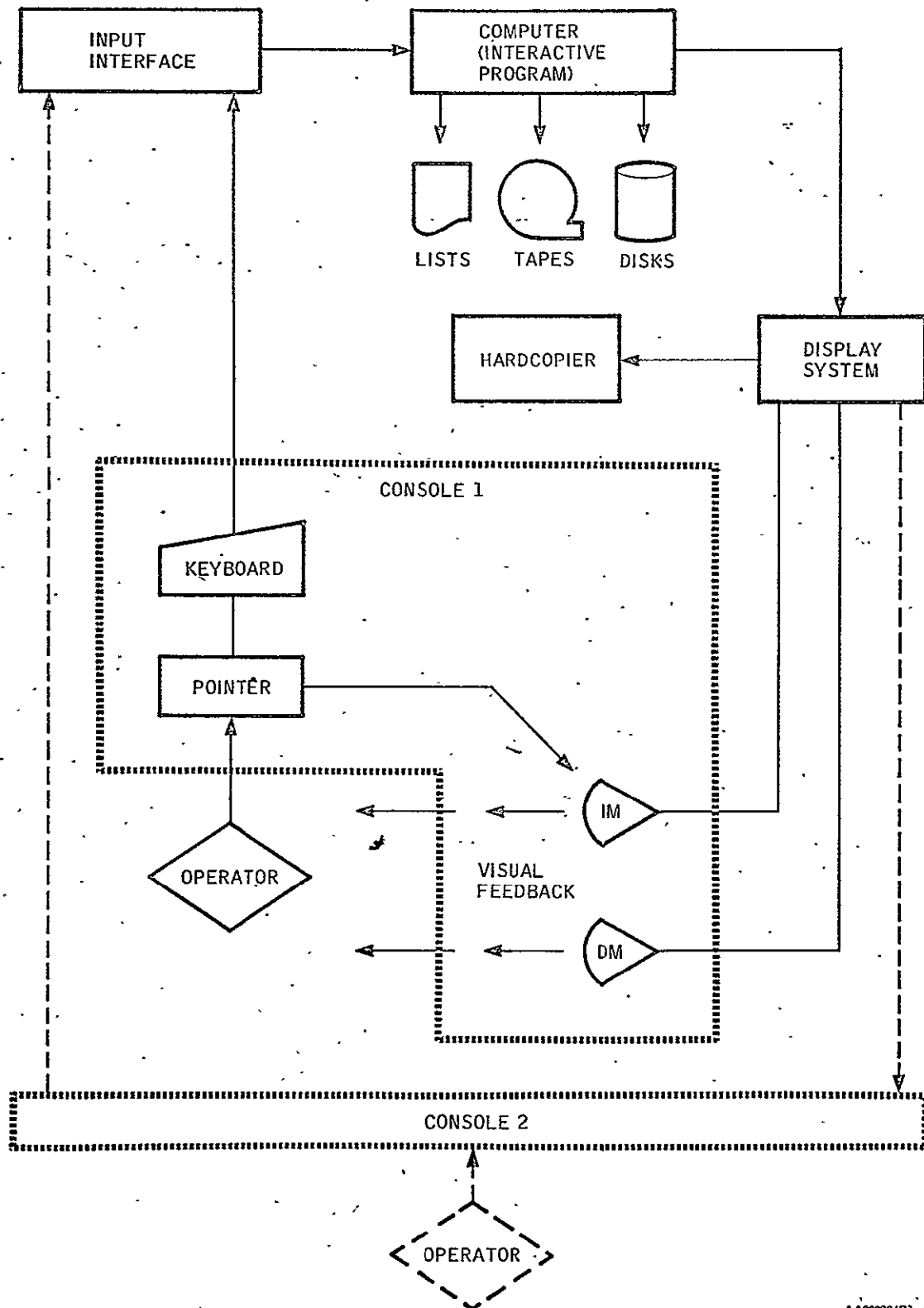
3.2 MONITORS

Two television monitors are used for each DRAFT console. The instruction monitor (IM) displays operator selection tables and control options. Feedback messages tell the operator what he has already accomplished and what options are next available. The display monitor (DM) is the work sheet of the DRAFT system. It presents exactly the format and content of the display as it is being designed and completed.

3.3 POINTER

The visible field on the DTE monitors is defined by the 612 x 439 coordinate positions at which visible dots may appear. A special pointer cursor is displayed on both monitors so that it points to the coordinate position desired.

The DRAFT pointer device, such as a Grafacon pen, provides the operator a means of controlling the movement of the pointer cursor on the display screen. The pointer device output is in terms of 1024 x 1024 coordinates which are scaled by the DTE display system to 612 x 439. A foot switch activates the input of pointer coordinates at a 10 per second rate. As the pointer (or pen) is moved over the tablet, the coordinate inputs change accordingly. The pointer cursor is displayed simultaneously on both monitors to inform the operator of his pointer position.



AA09909 (B) - 2

Figure 3-1 DRAFT II System Flow

3.4 ACTION SWITCH

The action switch provides the operator with a means of indicating to the system his choice of monitors and where on the screen he wishes to take action. The switch is polarized so that movement of the switch toward the IM on the left indicates action on the left or instruction monitor; movement of the switch to the right indicates action on the right or display monitor.

3.5 KEYBOARD

The keyboard provides for input of 128 character/symbol codes and various function codes (maximum of 128) to the DRAFT system. All standard typewriter keyboard functions are available as well as special functions such as the dynamic data (DYN) key, subscript ($\downarrow\frac{1}{2}$) key, superscript ($\uparrow\frac{1}{2}$) key, line up (\uparrow) key, line down (\downarrow) key, EOT key, and size keys 1 through 5. (Reference SE-09467.)

3.6 HARDCOPIER

The hardcopier is located in the immediate console area and produces copies suitable for documentation and reproduction purposes. The capability for selecting hardcopier output from either monitor on a console is a requirement.

3.7 SYSTEM RESPONSE TIMES

The maximum delay from the time of console input to the time of monitor display is 1/3 second. The maximum input update rate to which the system must respond is 10 per second per console. The maximum pointer cursor output update rates shall be 10 per second per console.

3.8 AUXILIARY FUNCTIONS

The capability for selecting hardcopy production from the IM or DM is provided on an auxiliary panel. An additional capability provides for suppressing either X or Y axis coordinate inputs from the pointer device. This provides for horizontal only or vertical only movement of the pointer cursor. A continuous cursor switch is also available for continuously inputting coordinates without holding down the footswitch.

SECTION 4

DRAFT DATA BASE

4.1 GENERAL

The DRAFT data base must be maintained on a permanent storage medium such that computer or peripheral failure will not result in the loss of more than the immediate work area. The following paragraphs define size and content of the data base.

4.2 DISPLAY LIBRARY "TABLE OF CONTENTS"

The display library "Table of Contents" (TOC) may contain from 1 to 1800 entries. There is one entry for each display in the display library and each entry consists of the MSK number, FCN, PCL, status letter, display TYPE, and mission number.

The TOC entries must be ordered in storage by increasing the magnitude of the MSK number, FCN number, and PCL. These constitute a unique identification for each display. A particular combination of MSK, FCN, and PCL may appear only once in the table. Reordering with each addition or deletion is required to maintain the table in order for the calling of TOC entries by MSK block number. The following paragraphs define each section of the TOC entry.

4.2.1 Manual Select Keyboard (MSK)

The MSK number consists of four numerals from 0000 to 2047 inclusive. The same MSK number may appear more than once with different combinations of FCN's and PCL's.

4.2.2 Format Control Number (FCN)

The FCN consists of four numerals from 0000 to 9999. It identifies the static (background) information of the displays. The same FCN may appear more than once with a different PCL each time.

4.2.3 Program Change Letter (PCL)

The PCL consists of one alphabetic letter from A through Z. It identifies changes or modifications to the program for displaying the dynamic data. If no changes have been made to the basic display program, the PCL is left blank. The same PCL may appear more than once with a different FCN or MSK each time.

4.2.4 Status Letter

The status letter may be any alphabetic letter A through Z. This field is searched for a "C" during output of completed displays.

4.2.5 Display TYPE

This display TYPE designator consists of three alphabetic letters A through Z, and one numeral 0 to 9. This field is referred to during output of FDS data to determine right or left adjustment of the coordinates field.

4.2.6 Mission Number

The mission number consists of a combination of five alphanumeric characters identifying missions applied to the display. Space for three different simultaneous mission numbers must be provided. This location must be referenced in outputting selected mission TOC listings or display library outputs.

4.3 DISPLAY LIBRARY

The display library contains from 1 to 1800 display files. Each file may contain the following types of information.

4.3.1 Header Information (Refer to Figure 5-14)

- A. DRK Title. Contains 26 alphanumeric characters divided into three 8-character groups by asterisks.
- B. Title. Contains 40 alphanumeric characters or spaces that are the same as the title on the display.
- C. Summary Message Enable Keyboard (SMEK). Contains two numerals varying from 01 to 99. SMEK identifies the call number of the summary message containing the displayed parameters.
- D. Size. Contains one numeral (1 thru 5) designating the basic size of alphanumeric characters for the display.
- E. Format Description Sheet Change (FDSC). Contains three numerals (1 thru 999) indicating that the FDS changed after programming of the display had started.
- F. Update Rate. Contains five numerals (1 thru 9999) indicating the time elapsed between updates in seconds.
- G. Sunflower Symbol (asterisk). Indicates loss of data appearing on the display. Three sunflowers may appear on a display and they are identified on the FDS with a 3-letter vehicle designator. They are typed on the IM in order of their display from left to right with commas separating each position. If no entry is made, a blank is assumed for that position. If any entry is made in position two or three, both commas are mandatory.
- H. Downlist Indicators. A one-letter indicator (x) to identify when a single downlist applies to the display. The following downlists are presently identified:
 - AGC - Power
 - AGC - Rendezvous

- AGC - Coast
- AGC - Update
- AGC - Program 22
- LGC - Power
- LGC - Rendezvous
- LGC - Coast
- LGC - Update
- LGC - Descent/Ascent
- Lunar Align.

- I. Comments. An extra 300 bytes is provided for comments or expansion of header data.

4.3.2 Static Data Alphanumerics

This entry contains the alphanumeric groups of the static or background data. A group consists of an XY coordinate, one or more character codes, and an EOT code. Character codes unique to the DTE display system are given in Appendix C.

The number of alphanumeric groups which must be stored by DRAFT is limited by the display system capacity in the following ways:

- A. The maximum number of character codes which may appear in a single group is limited by the number of characters which may be viewed at one time on the television monitor. For the DTE display system, this is 3570 size one characters.
- B. The smallest displayable group consists of the XY coordinate, one character code, and the EOT. The maximum number of such groups is limited by the DTE display system capacity of 1536 computer language words.

4.3.3 Static Data Lines (Vectors)

This entry contains lines (vectors) of the static background. Each line is defined by the XY coordinates of its two end points. The first XY point entered is the identifying coordinate by which the line is manipulated. The maximum number of such lines (vectors) is limited by the DTE display system capacity of 1536 computer language words. Lines for graphs and curves are grouped like entities to provide for recall and movement as a unit.

4.3.4 Dynamic Data Alphanumerics (D. Data)

This entry contains the alphanumerics of dynamic data groups and is similar to the static data alphanumerics. The maximum number of displayable groups is limited by the DTE display system capacity for 1024 computer language words. The maximum length of any group is 17 characters or symbols including the limit sense diamond. It is identified separately because it does not appear as part of the static (background) data output to either the Gerber tape or the DTE Diskpack. It does appear as part of the output of the FDS lists and tapes. PHO-TR147 refers to this as the dynamic data configuration in the FDS format field.

4.3.5 Format Description Sheet (FDS)

Entry of FDS information is divided into two categories. The first category provides for specifying the nature and location on the TV monitor of data to be displayed alphanumerically. The second category provides for specifying the nature and TV monitor plotting area of data to be displayed graphically. Each type of data is entered through an IM display and stored as part of the display file FDS data.

4.3.5.1 Alpha/D. Data FDS (Figure 5-5)

- A. External Name. Contains a maximum of 12 letters and numbers identifying the parameter.
- B. Type. Contains five characters, defining the type of dynamic data represented by the dynamic data symbols (e.g., decimal, octal, time, BLVL, etc.).
- C. Bilevel. Contains eight characters defining the "1" and "0" condition when BLVL is entered in the TYPE field above.

- D. Suppress Limits. Contains an "X" character entered when the parameter limit sensing is to be suppressed; otherwise it is blank.
- E. Vehicle. Contains one letter designating the vehicle data source for some parameters; otherwise it is blank.
- F. Comments. Contains 24 alphanumerics providing for comments related to programming the parameters.
- G. Sequence Number. Contains three numerals, 1 thru 999. The number is entered by the program and remains with the parameter until the parameter is deleted from the display.
- H. PCL. Contains the program change letter entered when changes to the dynamic data configuration or FDS data are made. PCL consists of one letter and must be changed by the operator.
- I. Size. Contains one numeral designating the character size if the dynamic data size is different from that given in the display header information.

4.3.5.2 Plot FDS (Figure 5-8)

The plot FDS data base may define any number of graphs subject to hardware constraints. Each graph may have up to nine X scales and nine Y scales. Each scale may have a maximum of nine associated parameters or external names. The program adds sequence numbers and keeps track of the axis (X or Y) with which a scale is associated. The following paragraphs outline the data required to define a graph.

A. Grid Data

- 1. X Minimum Coordinate. Contains four numerals defining the minimum or left X-axis coordinate of the graph in 1024 x 1024 coordinates. It may vary from 0000 to 1023.
- 2. X Maximum Coordinate. Contains four numerals defining the maximum or right X-axis coordinate of the graph in 1024 x 1024 coordinates. It may vary from 0000 to 1023.

3. Y Minimum Coordinate. Contains four numerals defining the minimum or bottom X-axis coordinates of the graph in 1024 × 1024 coordinates. It may vary from 0000 to 1023.
4. Y Maximum Coordinate. Contains four characters defining the maximum or top Y-axis coordinate of the graph in 1024 × 1024 coordinates. May vary from 0000 to 1023.
5. X Divisions. Contains three numerals defining the number of X-axis grid divisions. This is required for automatic graph construction but is not included in FDS outputs.
6. Y Divisions. Contains three numerals defining the number of Y-axis grid divisions. This is required for automatic graph construction but is not included in FDS outputs.

B. Scale Data

1. Scale Number. Contains one numeral (1 thru 9) identifying the scale. Scale numbering is from the grid outward.
2. EU MIN. Contains 14 characters which may be plus or minus signs, letters or numerals. Defines the left or bottom limit of a plot scale in engineering units. In case of reversed scales, it may be the largest numerical value.
3. EU MAX. Contains 14 characters which may be plus or minus signs, letters or numerals. Defines the top or right limit of a plot scale in engineering units. It may in the case of reversed scales be the smallest numerical value.

C. Parameter Data

1. External Name. May contain a maximum of 12 alphanumeric characters defining the parameters being plotted.
2. Label. May contain a maximum of 12 alphanumeric characters identifying the parameter.

3. VEH. Contains three alphabets identifying the vehicular source of the parameter.
 4. PLOT CHAR. Contains one character which may be any symbol in the DTE symbol library (maximum of 128). It is used as the plotting symbol.
 5. CHAR Size. Contains one numeral (1 thru 5) for the five possible plotting character sizes.
 6. SEQ. Contains a 3-digit sequence number entered by the program. May range from 001 thru 999.
 7. PCL. Contains single letter A through Z used to identify a change to the individual line.
 8. Comments. Contains 17 alphanumerics providing for comments related to programming the parameter.
- D. Curve Data. The curve EU points must be stored to provide for later curve modification. The following items are required for each curve.
1. Label. Contains 12 alphanumerics for labeling the curve.
 2. Interval. Contains 2 numerals (1 to 99) specifying the interval between points in 1024 x 1024 X coordinates.
 3. Symbol. Contains one DTE alphanumeric.
 4. Size. Contains one numeral (1 thru 5) for character size.
 5. # PTS. Contains a 3-digit numeral defining the number of points to be interpolated by the program from the points entered by the operator.
 6. INV. Contains one alphanumeric to tell the interpolation routine to invert.
 7. EU Point Table. Contains an X and Y axis list of engineering unit points, each point entry containing a maximum of 29 alphanumerics with or without sign. A capability for entering 50 points is required.

4.4 DTE DISKPACK TABLES

(14)

These tables are read into DRAFT storage for later output to the DTE Diskpack. They consist of the character font (dot matrix) table, the coordinate conversion table, and the diagnostic displays table. A capability for changing and updating each table must be available through either card or tape input. PHO-TR446, *DTE Background Disk Recording Requirements*, outlines in detail the data requirements for the character font (dot matrix) table and the coordinate conversion table.

4.5 ENTITY LIBRARY

The entity library consists of a TOC, static data storage and dynamic data storage. There is no requirement for storage of FDS data for entities. A capability for a minimum of 200 entities is required.

4.5.1 Entity TOC

The following items are required:

- A. ID Number. Contains three numerals 001 through 200.
- B. Entity Name. Contains 24 alphanumerics identifying the entity to the operator.
- C. Operator. Contains 10 alphanumerics identifying the operator responsible for creating the entity. (1)
- D. Date. Contains eight alphanumerics permitting the dating of entities created. (1)

4.5.2 Entity Static Data

(2)

Entities for static data may contain any combination of lines and alpha groups. The total number of lines plus alpha groups can not exceed 1536. In addition to the coordinates for the individual lines or groups, the XY coordinate reference for the entity will be stored to provide for the stored homing capability.

4.5.3 Entity Dynamic Data

2

Entities for dynamic data contain only alphanumeric symbol groups. The maximum number of groups for a single entity would be 1535. Each dynamic data entity is referenced to an XY coordinate just as static data. Separate identification of dynamic data entities is required to allow linking to FDS input requirements.

SECTION 5

PROGRAM OPERATIONAL DESCRIPTION

5.1 GENERAL

The following operational description is intended to outline, with a moderate amount of detail, the functional requirements of the DRAFT system program and the level of interaction desired between it and the operator. Figures are included both to illustrate operator options and to specify required data.

This document establishes a minimum capability requirement which may be supplemented during implementation. The final result desired is an easily comprehended display design system.

5.1.1 System Initialization and Termination

3

The initialization and termination of the DRAFT operation must be simple and straightforward. Termination requires the creation of backup records to guarantee against loss of display and entity files.

- A. Initialization. Initialization of the DRAFT system is possible from either DRAFT console. A console keyboard entry causes the program to display the major decision matrix (Figure 5-1) on each console IM and the message CONSOLE READY on each console display monitor.
- B. Termination. Termination of DRAFT operation is from the keyboard. The termination process requires the recording of the DRAFT display library, display library TOC, entity library, and entity library TOC on a backup medium such as a tape or disk. Provisions for recovery of these files from the backup medium and reconstruction on the working disk are required. Fail safe procedures are provided for recording the backup libraries should both consoles go down during DRAFT operation.

5.1.2 Cursor Symbols

The following three types of cursors are used as feedback devices for informing the operator of his position on the IM and DM. The

D/TV X 0000		SIZE 0		DTE X 0000		
COORD Y 0000				COORD Y 0000		
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
◊	◊	◊	◊	◊	◊	◊

Figure 5-1 Major Decision Matrix

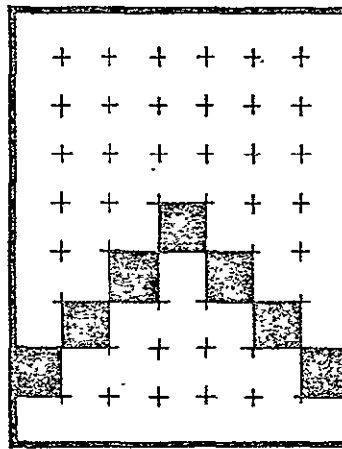
alpha construct cursor and alpha modify cursor use different symbols but otherwise function similarly. Operation of the alpha construct and alpha modify cursor disables the pointer cursor function until an EOT terminates the group under construction or modification.

- A. Pointer Cursor. The pointer cursor (DTE 3048) is a caret-like symbol whose apex dot is at the center of a 7 x 9 character matrix (Figure 5-2). The apex or tip dot points to and lies on the exact coordinate position of the symbol and corresponds with the coordinate input of the pointer device. (Grafacon).
- B. Alpha Construct Cursor. The alpha construct cursor (DTE 0068) is a box symbol of the same size as that entered by the operator from the keyboard. It consists of the perimeter dots of the character matrix. The alpha construct cursor is under keyboard control and thus represents the exact area in which a symbol will appear when typed.
- C. Alpha Modify Cursor. The alpha modify cursor (DTE-2008) is an underline symbol of the same size as the keyboard-entered character size. It consists of the bottom row of bits of the DTE character matrix. It operates under keyboard control and may be spaced forward and backward under an alpha group without its obscuring the symbols to be modified. It will change in size to correspond with the size of the character to be modified.

5.1.3 Cursor Homing

Cursor "homing" is the initial placement of a cursor symbol or DM tag at a particular location or coordinate position on the DM screen. Selection of a homing option does not affect the movement of the pointer cursor as it follows the changing inputs of the pointer device. Only the alpha construct cursor, alpha modify cursor and DM tags are homed to a particular location. Homing is provided for the construct, move, and copy operations on entities, alpha/dynamic data and line-ellipses. Homing is also provided for the move and copy operations on graphs. The following homing options provide for accurate and flexible positioning of the display data.

- A. Coordinate Homing. Places the cursor symbol at the exact XY coordinates input from the pointer device when the action switch is depressed.
- B. ANK Homing. Places the cursor symbol at the exact coordinate typed in on the keyboard.



AA09909(A)-1

Figure 5-2 Pointer Cursor on the 7 x 9
Character Dot Matrix

- C. Character Box Homing. Places the cursor symbol at a standard character box coordinate nearest the input coordinate. The exact character box coordinate is determined by the computation outlined in Appendix B. (4)
- D. Stored Homing. Applies only to the recall of entities. This places the symbol or entity at the same location as when it was stored. (2)

5.1.4 Selection Tracks

Selection tracks provide the operator with reminders of immediate previous actions. As the DRAFT operator chooses options on the IM, the DRAFT program leaves "tracks" consisting of an "X" character or similar symbol. The symbol is displayed each time the IM is selected with the action switch and remains displayed until altered by another selection at the same level of operation.

5.1.5 DM Tags

The tag or pickup point visually identifying a line, entity, or alpha group is the "box" symbol (Appendix C). Where the tag identifies a line, it shall be size one and be shifted one character space from the line start point. Where the tag identifies an alpha group or entity, it shall be one size larger than the current keyboard selected size with the exception of size 5 which can be no larger. It shall appear at the same coordinate as the first (start print) character of the group and thus outline it. The DRAFT program shall provide for pickup of the group when any area within the box is indicated with the pointer cursor.

5.1.6 Pointing

Pointing is defined as moving the pointer device pen so that the displayed pointer cursor rests at the desired location on the screen while the action switch is depressed toward the DM or IM. Action switch operation on the IM permits selection of program options while action switch operation on the DM permits selection or entry of XY coordinates. The terms "pointing" and "selection" are synonymous.

5.1.7 Keyboard Functions

The following paragraphs outline the operator/program interaction for typewriter keyboard functions. Table 5-1 lists the effect of keyboard functions on the alpha cursor, alpha cursor coordinates, and the group under construction.

A. ACTION: Depress a symbol or alphanumeric character key.

RESPONSE: The program displays the character on the IM or DM at the alpha construct cursor or modify alpha cursor location. If on the DM, the character size is that previously selected by the operator. If on the IM, the character size is that defined by the programmer. As each character is displayed at the cursor position the cursor is advanced to the next character position. If the cursor has been backspaced to previously constructed characters within the group, they will be replaced with the new character.

B. ACTION: Depress a character size key. (5)

RESPONSE: The program enters the new size which remains in effect until the next character size key is depressed. Character size effects character spacing, backspacing, line up and line down, margin return, carriage return, subscript, and superscript functions.

C. ACTION: Depress the EOT key.

RESPONSE: The program ends the construction or modification of the current group of characters. The cursor does not advance.

D. ACTION: Depress the increment (INC) key. (5)

RESPONSE: The program changes from a spacing constant controlled by the character size which has been entered to a single 1024 x 1024 increment

TABLE 5-1
KEYBOARD FUNCTIONS

KEYBOARD FUNCTION	EFFECT ON CURSOR		EFFECT ON GROUP UNDER CONSTRUCTION	
	CHANGES CURSOR SPACING	CHANGES CURSOR COORD.	TERMINATES, ENTERS EOT IN DATA BASE	ENTERS DATA BASE DIRECTLY
LINE UP (↑)		YES	YES	
LINE DOWN (↓)		YES	YES	
SUPERSCRIPT ($\uparrow\frac{1}{2}$)		YES	YES	
SUBSCRIPT ($\downarrow\frac{1}{2}$)		YES	YES	
TAB		YES	YES	
SIZES 1-5	YES		YES	ENTERED IN NEXT GROUP.
SPACE		YES		ENTERS BLANK
BACKSPACE (←)		YES		
DYN			YES	
CS	YES			
INC	YES			
BLANK		YES		YES
MR		YES		YES
EOT			YES	YES
CR		YES	YES	
<div> <div> TAB SET TAB CLEAR INSERT DELETE </div> <div> } </div> <div> THESE FUNCTIONS REQUIRE SPECIAL PROGRAMMING </div> </div>				

constant. Thus when the SPACE, backspace (\leftarrow), line up (\uparrow) and line down (\downarrow) keys are struck, the alpha cursor moves only one coordinate position for each activation.

(5)

E. ACTION: Depress the character space (CS) key.

(5)

RESPONSE: When this key is depressed, the program utilizes a spacing constant proportional to the character size which has been entered. Column K_5 in Appendix B lists X and Y spacing constants for each character size. The distance moved for SPACE, backspace, line up, line down, subscript, and superscript keys will be controlled by these character spacing (CS) constants.

F. ACTION: Depress the delete (DEL) key.

(5)

RESPONSE: The program deletes the character at the cursor coordinate and moves the following characters and blanks in the group one character space left.

G. ACTION: Depress the carriage return (CR) key.

RESPONSE: The program returns the cursor to the left most character box for that size and one line lower. Appendix B lists the leftmost character box coordinate for each size under K_0 for X coordinates.

H. ACTION: Depress the margin return (MR) key.

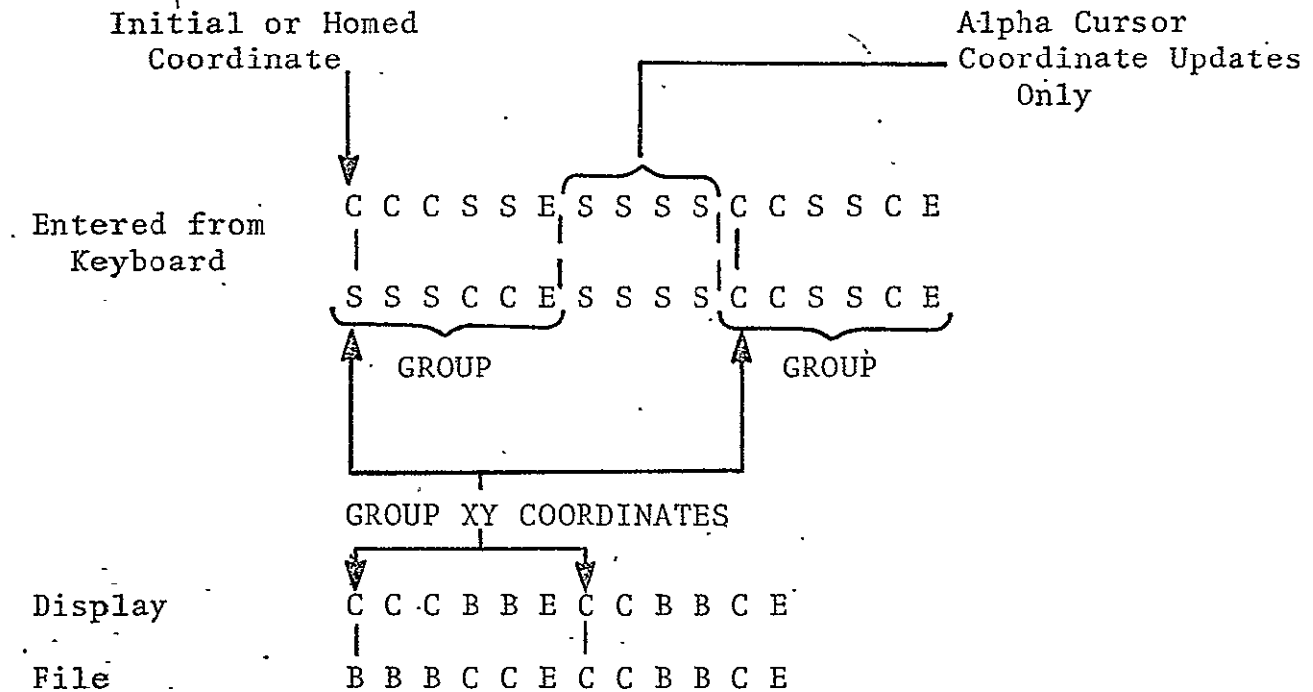
RESPONSE: The program returns the cursor to the start coordinates of the current group one line down without terminating the group. The MR code is recognized as a symbol code by the DTE, but requires special programming to move the cursor to the appropriate location.

I. ACTION: Depress the subscript ($\downarrow\frac{1}{2}$) key.

(5)

RESPONSE: The program terminates the group under construction with an EOT and moves the cursor down one-half the character height of the character size currently entered.

- J. ACTION: Depress the superscript ($\uparrow\frac{1}{2}$) key. (5)
- RESPONSE: The program terminates the group under construction and moves the cursor up one-half the character box height of the character size currently entered.
- K. ACTION: Depress the TAB SET key.
- RESPONSE: The X coordinate of the cursor is entered in the tabulate table. A maximum of 20 entries will be possible in the tabulate table.
- L. ACTION: Depress the TAB CLEAR key.
- RESPONSE: The X coordinate of the cursor position is removed from the tabulate table if it is present. No other tabulate coordinates are changed.
- M. ACTION: Depress the TAB key.
- RESPONSE: The program moves the cursor to the next greater tabulate table X coordinate. If an alpha group is under construction, the program will terminate the current group and the next character symbol will begin a new group.
- N. ACTION: Depress the SPACE bar.
- RESPONSE: The program moves the cursor one character space to the next greater X coordinate for the size entered. If the cursor coordinate is at a standard character box X coordinate, the next spaced coordinate will be at a standard character box X coordinate. If the cursor is at a non-standard coordinate, the next spaced coordinate will be at an equivalent properly spaced non-standard character coordinate. Note that the program must substitute blanks when SPACE codes appear within Alpha/D. Data groups. In the following examples of spacing within and outside of Alpha/D. Data groups, "C" stands for a character or symbol, "S" stands for a SPACE, "E" stands for EOT, and "B" stands for BLANK.



- O. ACTION: Depress the backspace (←) key.
- RESPONSE: The program moves the cursor one character space to the left under the same rules as for SPACE.
- P. ACTION: Depress the line up (↑) key.
- RESPONSE: The program terminates the group under construction and moves the cursor up one character line from its current position. If on a standard character box coordinate before moving, it will be on a standard character box coordinate after the moving. If at a non-standard coordinate location, it will be at a corresponding non-standard coordinate location after moving.
- Q. ACTION: Depress the line down (↓) key.
- RESPONSE: The program terminates the group under construction and moves the cursor down one character line from its current position. If on a standard

character box coordinate before moving, it will be on a standard character box coordinate after the moving. If at a non-standard coordinate location, it will be at a corresponding non-standard coordinate location after moving.

R. ACTION: Depress the BLANK key.

RESPONSE: The program moves the cursor one character space to the right. If a character is present it will replace the character with a blank.

S. ACTION: Depress the insert (INS) key.

5 6

RESPONSE: The program inserts the next character keyed at the cursor location and moves the character at that location and each succeeding character in the group one character space right. An error message will be provided if this action moves the group outside the display limits.

5.1.8 IM Permanent Displays

The IM permanent displays are always present on the monitor (Figure 5-1). They are the major decision matrix, the DTE and D/TV XY coordinate displays, and the character size display. Other displays appear and disappear during operator/program interaction.

- A. Major Decision Matrix. The major decision matrix presents the functions relating to complete display records. Provisions are made for erasing the display monitor (DMERASE), deleting a display from the library (DELETE DISPLAY), designing a display (DESIGN DISPLAY), saving a display in the library (SAVE DISPLAY), calling a display from the library (CALL DISPLAY), outputting the display and its supporting data (OUTPUT EXT) to tapes, printers or disks, and inputting (EXT INPUT) of displays, diskpack tables and test data from cards or tapes.
- B. Coordinate Display. The coordinate location of the pointer cursor which is displayed on both screens is given decimally on the IM in both D/TV 1024 x 1024 coordinates and DTE 612 x 439 coordinates.

- C. Size Display. The character size entered at the keyboard is shown to provide a visual reminder to the operator of the size he has selected and thus reduce the number of repetitious size entries. The five sizes are specified in SP-08873A.

5.1.9 IM Secondary Displays

Secondary displays appear in response to operator decisions and actions. Each display must convey sufficient information to the operator to permit him to make further decisions or optional selections. Figures defining the data required in these displays are included in each of the following sections.

5.1.10 Error Messages and Error Recovery

6

The DRAFT II system must always keep the operator informed of its status and the operators next action or decision should always be clearly defined. Sufficient error messages must be provided to the operator to inform him of illegal actions. The capability must exist for the operator to cancel any series of actions and return to the major decision matrix at any time.

When any part of a group, entity, or graph is moved beyond the display limits (1024 x 1024), an error message notifies the operator of the fact. Data should not be lost from the data base and full recovery of the group, entity or graph is possible. Use of the "display window" concept is preferred.

5.2 DESIGN DISPLAY

The function of display design is to create the lines, curves, and alphanumerics necessary to design a display on the DM. Figure 5-3 appears on the IM when DISPLAY DESIGN is selected. The following paragraphs outline the design functions in terms of general requirements and operator/program interaction. Flow charts and IM displays are used to illustrate the most important operational requirements. Box symbols are used on the IM displays to indicate operator or program entered data.

5.2.1 Alpha/Dynamic Data

In this mode, alpha/dynamic data characters are entered from the keyboard and displayed on the DM or IM as they are typed. A static data group is defined by the coordinates of the first symbol and the following EOT code. A dynamic data group is defined by striking the DYN key before and after typing in the groups dynamic symbols, but the DYN key does not move the cursor. Each group is constructed and manipulated independently, but they may be contained within and be part of an entity. Figure 5-4 and the following paragraphs further define the operator/program interactions.

5.2.1.1 CONSTRUCT ALPHA/DYNAMIC DATA

A. ACTION: Point to CONSTRUCT ALPHA/DYNAM (Figure 5-3)

RESPONSE: The program adds the following display to IM (Figure 5-3) providing the option to select the type of cursor homing desired.

SELECT CHARACTER SIZE ON ANK, THEN
SELECT HOMING OR TYPE IN COORDINATES

CHARACTER ☐ COORDINATE ☐

If coordinates are typed, the alpha cursor is presented at the exact coordinates. If coordinate homing is selected, the alpha cursor is presented at the coordinate indicated with the pointer. If character homing is selected, the program

D/TV X 0000		SIZE 0		DTE X 0000		
COORD Y 0000				COORD Y 0000		
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
0	0	0	0	0	0	0

	CONST	MOVE	COPY	MODIFY	ERASE	CALL	END	STORE	DELETE
ENTITY	0	0	0	0	0	0	0	0	0
ALPHA/ DYNAM	0	0	0	0	0				
LINE- ELLIPS	0	0	0		0				
GRAPH	0	0	0	0	0				
CURVE	0			0	0				

Figure 5-3 Display Design Matrix

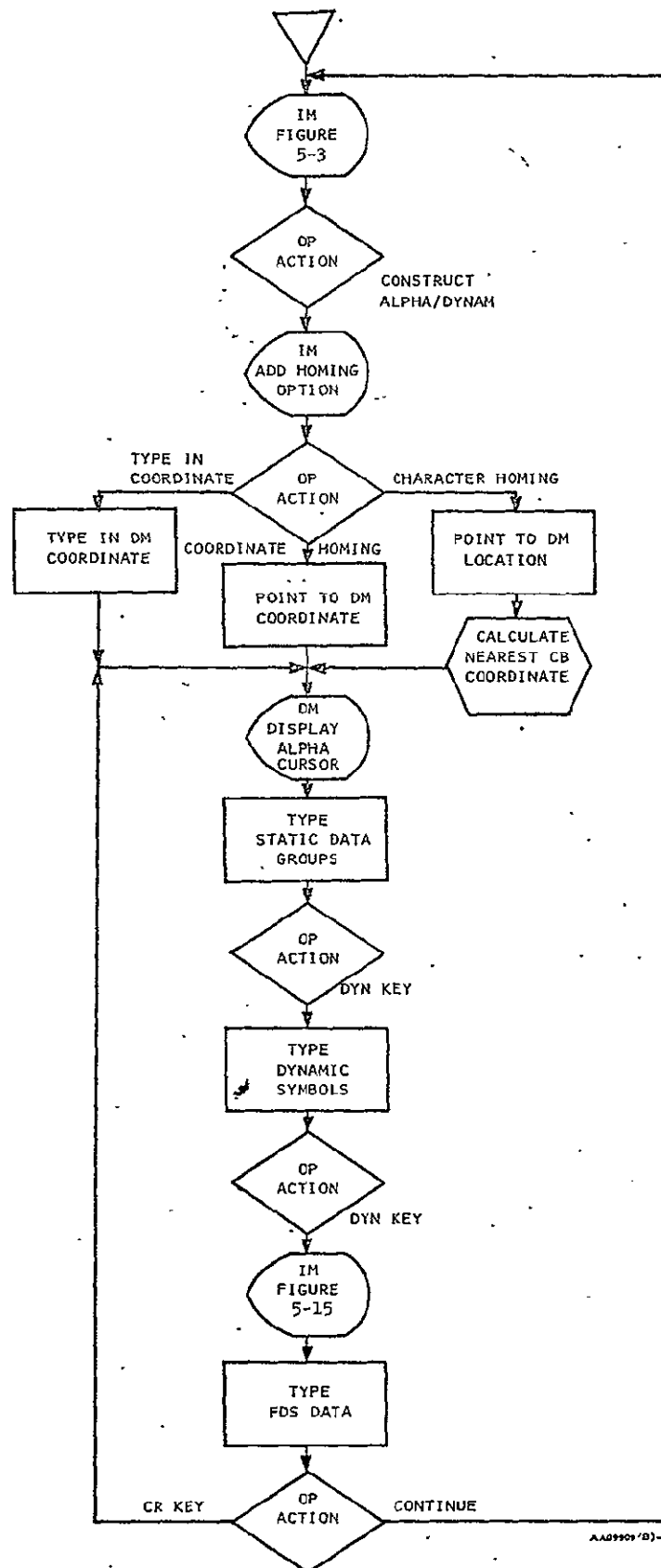


Figure 5-4 CONSTRUCT ALPHA/DYNAM

calculates the character box center nearest to the pointer coordinate from the character size selected and presents the alpha cursor at that location. Appendix B details the formula for calculating character box centers.

B. ACTION: Type alphanumeric static data. (5)

RESPONSE: The program displays the data starting at the alpha cursor location. As each character appears, the cursor advances to the next character position. A group is ended by striking any of the following keys: EOT, TAB, DYN, ↑, ↓, ↑ $\frac{1}{2}$, ↓ $\frac{1}{2}$, and sizes 1 through 5.

C. ACTION: Strike DYN key first time.

RESPONSE: The program does not advance the alpha cursor and dynamic data symbols may then be typed. The DYN key identifies the data as dynamic, not static.

D. ACTION: Strike DYN key second time.

RESPONSE: The program ends the dynamic data group with an EOT code but does not advance the DM alpha cursor. Figure 5-5 appears on the IM with the alpha cursor in the first FDS field. The operator may then enter FDS data for the dynamic data group. The operator is given the option to point to CONTINUE and return to the design matrix or push the CR key and return to the DM at the last alpha cursor position. Note that the sequence (SEQ) number, format and XY coordinate entries are program originated. All other alpha FDS entries are made by the operator.

5.2.1.2 MOVE ALPHA/DYNAMIC DATA (7)

A. ACTION: Point to MOVE ALPHA/DYNAM (Figure 5-3).

RESPONSE: Tags appear on alpha/dynamic data groups on the DM. The option is displayed on the IM to select the type of cursor homing desired.

D/TV	X		COORD Y	SIZE	DTE	X		COORD Y
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/> ^	<input type="checkbox"/>

	CONST	Merge	COPY	MODIFY	ERASE	CALL	END	STORE	DELETE
ENTITY	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
ALPHA/DYNAM	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>				
LINE-ELLIPS	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>				
GRAPH	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>				
CURVE	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>				

ALPHA FDS

EXTERNAL NAME FORMAT SIZE TYPE COORD: X Y SUPPRESS LIMITS VEHICLE BILEVEL COMMENTS SEQ PCL

LINE UP OR LINE DOWN TO PAGE.
STRIKE CR KEY TO RETURN TO DM

CONTINUE

Figure 5-5 Alpha FDS Display

B. ACTION: Select the homing option desired. Point to the tag of the static alpha data group to be moved and then point to the desired new location or type in the XY coordinates.

RESPONSE: The group is moved to the new location. A series of moves may be made without reselecting the design matrix or homing technique. An error message will be returned if the operator attempts to move the group out of the display limits.

C. ACTION: Select the homing option desired. Point to the dynamic data group which is to be moved and then to the desired new coordinates or type in the new coordinates.

RESPONSE: The group is moved to the new location. A series of moves may be made without reselecting the design matrix or homing technique. An error message is returned if the operator attempts to move the group out of the display limits.

5.2.1.3 COPY ALPHA/DYNAMIC DATA

7

A. ACTION: Point to COPY ALPHA/DYNAM (Figure 5-3).

RESPONSE: DM tags are displayed on each alpha/dynamic data group. The option to select character or coordinate homing is presented.

B. ACTION: Select the homing option desired. Point to tag of static data alpha group to be copied and then to the desired new location or type in the new coordinates.

RESPONSE: The program copies the data group at the desired location.

C. ACTION: Select the homing option desired. Point to tag of dynamic data group on DM to be copied.

RESPONSE: The program presents the alpha FDS on the IM. (Figure 5-5).

D. ACTION: Point to the desired location of the new dynamic data group.

RESPONSE: The program copies the dynamic data at the indicated location. Data may then be entered in the new FDS line items and the operator may either make another copy by depressing the CR key and returning to the DM or he may select CONTINUE and return to the design matrix (Figure 5-3).

5.2.1.4 ERASE ALPHA/DYNAMIC DATA

A. ACTION: Point to ERASE ALPHA/DYNAM

RESPONSE: Tags appear on the static and dynamic groups.

B. ACTION: Point to tag of alpha or dynamic data group to be erased.

RESPONSE: Program erases group from DM and deletes entry in FDS area if dynamic data.

5.2.1.5 MODIFY ALPHA/DYNAMIC DATA

A. ACTION: Point to MODIFY ALPHA/DYNAM (Figure 5-3)

RESPONSE: Tags appear on static and dynamic data groups on DM.

B. ACTION: Point to tag of static data group to be modified.

RESPONSE: The alpha modify cursor appears beneath the first character of the group. The alpha modify cursor may be spaced or backspaced until under the character of the group to be modified. The character may then be erased or replaced by another character. Additional characters may also be added to the group.

C. ACTION: Point to tag of dynamic data group to be modified.

RESPONSE: The alpha modify cursor appears beneath the first symbol of the group and the alpha FDS line items appear on the IM (Figure 5-5).

D. ACTION: Type in changes or additions to the dynamic data.
Then strike EOT key.

RESPONSE: The alpha cursor appears on the IM and changes may be made to the operator entered items of the alpha FDS. Depressing CR key returns the operator to the DM or he may leave the mode by selecting CONTINUE and returning to Figure 5-3 on the IM.

5.2.2 Line/Ellipse

7

This design option allows the operator to construct lines or ellipses either singly or joined end-to-end. The option for specifying an interval number provides for either constructing DASH lines or placing symbols along the line at that interval.

Circles or ellipses may be constructed by specifying the number of line (vector) end points and the XY semi-axis distance in 1024 x 1024 increments. When symbols are specified for circles or ellipses, the symbol is displayed where the junction of a pair of lines would be. The homing option provides for locating the lines or centering the ellipses at the character box centers as well as typing in the coordinates or pointing. Move, copy, and erase options provide manipulation of individual lines (vectors).

5.2.2.1 CONSTRUCT LINE/ELLIPSE (Figure 5-6)

7

The following display is added to IM (Figure 5-3) requiring the operator to select the construction of lines or ellipses and indicate the type of line appearance desired.

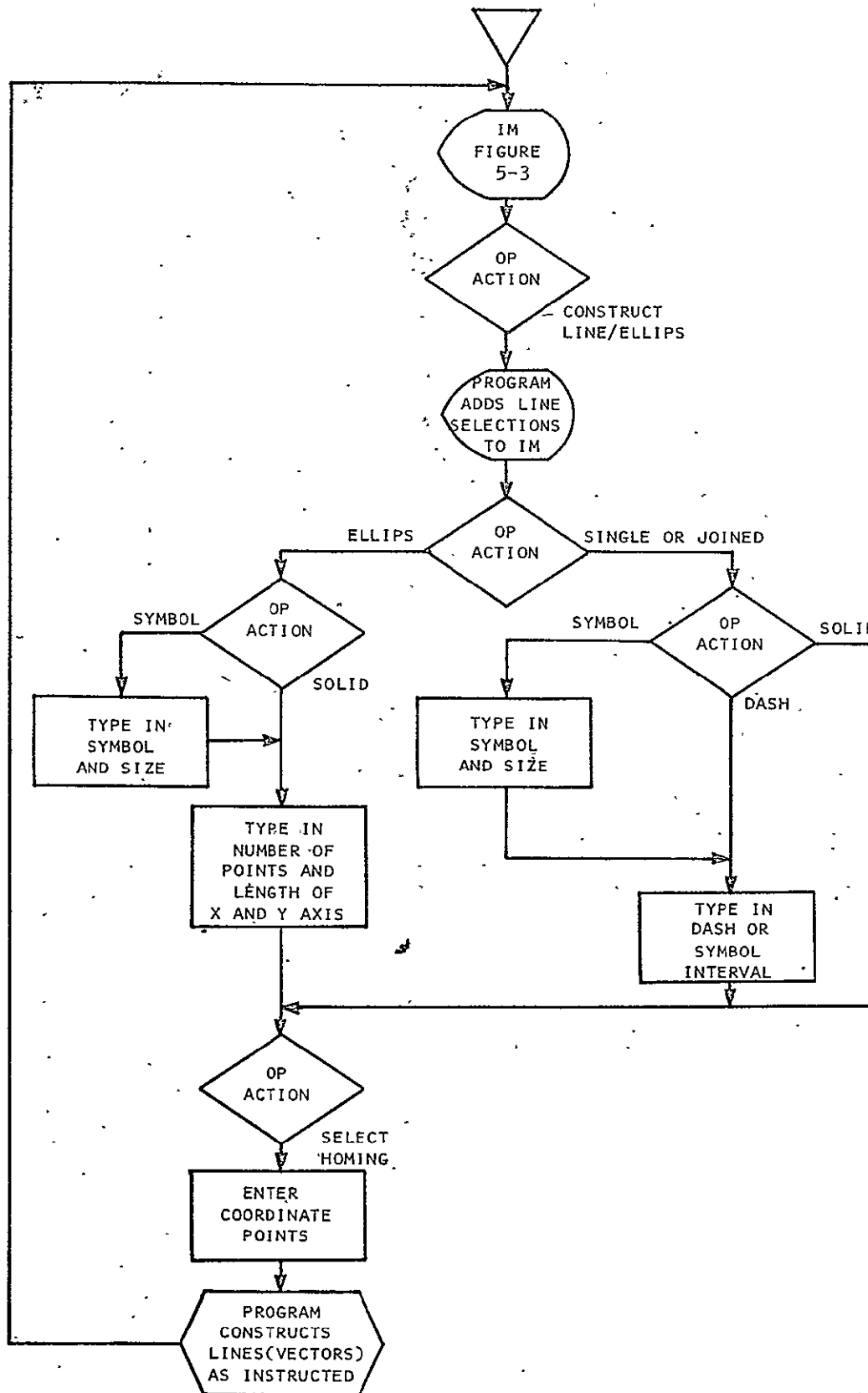
SINGLE	JOINED	ELLIPS	SYMBOL	NUMBER	X AXIS	Y AXIS
o	o	o				

SELECT CHARACTER SIZE ON ANK, THEN

SELECT HOMING OR TYPE IN COORDINATES

CHARACTER ☐

COORDINATE ☐



AA29909(B)-4

Figure 5-6 CONSTRUCT LINE/ELLIPSE

Selection of SINGLE instructs the program to construct a single line between each succeeding pair of XY coordinates, i.e., between point one and point two, point three and point four, point five and point six, etc. As the first point of each single line is entered, the size 1 box symbol appears at the first XY coordinate. When the second point of the line is entered, the line appears and the box symbol is removed.

Selection of JOINED instructs the program to construct a series of lines between each XY coordinate entered, i.e., between point one and point two, point two and point three, point three and point four, point four and point five, etc. As the first point of each JOINED line is entered, the size 1 box symbol appears at that XY coordinate. As each subsequent XY coordinate point is entered, the box symbol advances so that it always marks the last entered point.

After selecting the type of line construction desired, the operator must choose the line appearance desired. If a solid line is desired, the operator proceeds to select a homing option or type in coordinates. The program then constructs a single line between each pair of coordinates entered.

If a DASH line is desired, the operator points to the number box and the program places the alpha cursor in the box. The operator types in the X coordinate interval desired. (Interval is defined as the distance between the beginning points of two succeeding DASH lines or the distance between symbol placement coordinates.) The operator selects a homing option and proceeds to enter coordinate points. The program constructs a DASH line by adding line end points where needed.

If a symbol line is desired, the operator points to the SYMBOL box and the program places the alpha cursor in the box. The operator types in the symbol and size (e.g., V and 3), tabs to the NUMBER box, and enters the X coordinate interval desired between symbols. A homing option is then selected and coordinate points entered. The program constructs a line of symbols centered about the line at the specified interval.

Selection of ELLIPS provides for the construction of ellipses or circles. (Refer to Appendix D for the ellipse routine requirements.) A circle is a special case of the ellipse having an equal coordinate distance specified for both X and Y semi-axis. Note that the operator will type in the X and Y semi-axis distance in terms of an X coordinate number. The program must convert to equivalent Y-axis coordinates to achieve equal real lengths on the display screen.

Either solid lines or symbols may be used to achieve the desired appearance. If a solid line ellipse is desired, the operator points to the NUMBER box and the program displays the alpha cursor in the box. The operator must type in the number of points to be used in constructing the ellipse. The operator then tabs to the X and Y axis boxes to enter the semi-axis coordinate distances. A homing option is selected and the program constructs the ellipse centered about the coordinate specified.

If a symbol ellipse is desired, the operator points to the symbol box and the program places the alpha cursor in the box. The operator may then enter the symbol and size desired. Tabbing to NUMBER and X and Y axis boxes provides for entry of the number of points and the semi-axis coordinate distances. The operator selects a homing option and specifies the ellipse center. The program then constructs the ellipse at the desired location.

5.2.2.2 MOVE LINE/ELLIPSE

7 8

When this option is selected, the starting points of all lines on the DM are tagged. Each tag is displaced along the line, one character space from the starting point. The operator points to the starting point tag for the line to be moved, selects a homing option, and then points to the destination. The destination point may also be entered from the keyboard. Although the operator "picks up" the line at the tag point, the line end point is placed at the specified location. An unlimited series of moves may be made once a line has been selected, but pointing to another line ends the move capability. Another line may then be moved by indicating its starting point and destination without returning to the display design matrix.

5.2.2.3 COPY LINE/ELIPSE

7 8

This is handled exactly as the MOVE LINE except that the original line is not erased. After the line and homing option is selected, each succeeding coordinate pointed to becomes the origin for a duplicate until another line is selected.

5.2.2.4 ERASE LINE/ELIPSE

When this option is selected, tags appear near the starting points of all lines on the DM. The operator points to the tag of the line to be erased and the program removes it from the DM.

5.2.3 Graphs

9

Selection of this design option provides for program construction of a graph on the DM. The graph is constructed to be treated as a unit during moving, copying, and erasing. Any number of graphs may be constructed subject to hardware limitations.

5.2.3.1 CONSTRUCT GRAPH

A. ACTION: Point to CONSTRUCT GRAPH (Figures 5-3 and 5-7).

RESPONSE: The program replaces the design matrix with the plot FDS (Figure 5-8) and places the alpha cursor in the grid data area. The plot FDS grid data area provides for entry of the X and Y limits in 1024 x 1024 coordinates and for specifying the number of grid divisions in X and Y. Displays with multiple graphs have multiple plot FDS.

B. ACTION: Type in minimum and maximum XY coordinates and the number of X and Y divisions. Data entry is completed with EOT.

RESPONSE: The program checks for complete data entry. If data is incomplete the program returns the message CHECK ALL DATA ENTRIES to the IM. If the data is complete the program constructs the grid on the DM and stores the XY coordinate limits. Selection of CONTINUE either returns the program to IM or the operator may line down and enter data in the scale data or parameter data areas.

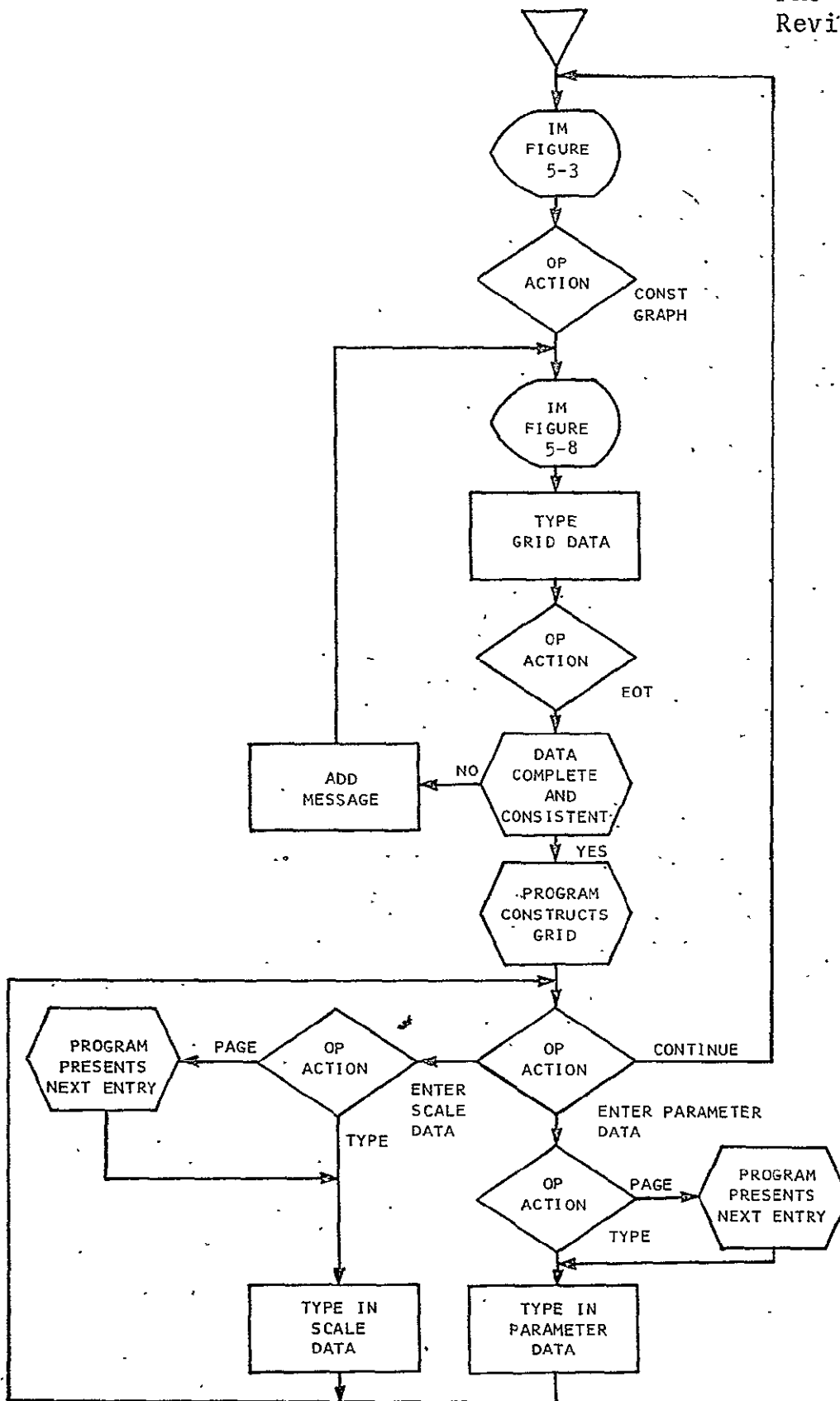


Figure 5-7 CONSTRUCT GRAPH

D/TV X <input type="text"/>		SIZE <input type="text"/>		DTE X <input type="text"/>	
COORD Y <input type="text"/>				COORD Y <input type="text"/>	

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

PLOT FDS		X-AXIS	Y-AXIS
GRID	COOR MIN	<input type="text"/>	<input type="text"/>
DATA	COOR MAX	<input type="text"/>	<input type="text"/>
	DIVISIONS	<input type="text"/>	<input type="text"/>

SCALE	EU MIN	<input type="text"/>	<input type="text"/>
DATA	EU MAX	<input type="text"/>	<input type="text"/>
	SCALE #	<input type="text"/> <input type="checkbox"/> PAGE UP	<input type="text"/> <input type="checkbox"/> PAGE UP
		<input type="checkbox"/> PAGE DN	<input type="checkbox"/> PAGE DN

PARAM	EXT NAME	<input type="text"/>	<input type="text"/>
DATA	LABEL	<input type="text"/>	<input type="text"/>
	VEH	<input type="text"/>	<input type="text"/>
	PLOT CHAR	<input type="text"/>	<input type="text"/>
	CHAR SIZE	<input type="text"/>	<input type="text"/>
	SEQ #	<input type="text"/> <input type="checkbox"/> PAGE UP	<input type="text"/> <input type="checkbox"/> PAGE UP
	PCL	<input type="text"/> <input type="checkbox"/> PAGE DN	<input type="text"/> <input type="checkbox"/> PAGE DN
	COMMENTS	<input type="text"/>	<input type="text"/>

CONTINUE ☐

Figure 5-8 Plot FDS

Scale data defines the engineering unit (EU) limits for both the X and the Y axis scales. Paging provides for definition of nine scales on each axis of the graph. The scale number is entered by the operator. When scale data is paged to an undefined scale, a blank parameter data area is presented; when scale data is paged to a previously defined scale, the first parameter entry for that scale is presented in the data area. Parameter data defines the external name, label, and vehicular source of data to be plotted on the corresponding graph scale. If a character is to be plotted, the character and character size are entered for either the X or Y axis, but not for both.

The PCL may be entered if needed and nine sets of parameter data may be entered for each scale by use of the paging option. The program assigns sequence (SEQ) numbers to the parameters in order of their entry. Sequence numbers 011 through 099 identify the X axis parameters; sequence numbers 111 through 199 identify the Y axis parameters. The tens position indicate the scales numbered 1 thru 9 and the units position indicate the parameter entries 1 thru 9. Note that the scale number and sequence number tens position will always be the same. Scale data will not change when parameter data is paged.

Two special cases of grid construction should be noted. When a one is entered in divisions for both X and Y, a rectangle is constructed at the specified limits. When zero is entered in divisions for both X and Y, the grid construction routine is bypassed. Coordinate limits and divisions are always specified. ⑨

5.2.3.2 MOVE GRAPH

When MOVE GRAPH is selected, homing options appear on the IM and tags appear on the origin (minimum XY coordinate) of each grid on the DM. The operator may then move the grid as a unit by pointing first to the graph origin tag and then to the desired destination position. Selection of a tag causes the program to erase the other tags and present the plot FDS (Figure 5-8). Successive moves should be possible until another or the same design option is selected. On each successive move the program updates the coordinate limits and shows the new limits in the grid data area. Curves already constructed as part of the graph will be moved with the grid.

5.2.3.3 COPY GRAPH

When this design option is selected, homing options appear on the IM and tags appear at each grid origin (minimum XY coordinate) on the DM. A particular grid is selected by pointing to its origin. The program presents Figure 5-8 on the IM. The destination of the duplicate is then pointed to on the DM and the program constructs the duplicate grid. The new coordinate limits are displayed in the grid data area and other FDS entry areas are blanked. The operator may then enter scale data and parameter data as he would under CONSTRUCT GRAPH.

5.2.3.4 MODIFY GRAPH

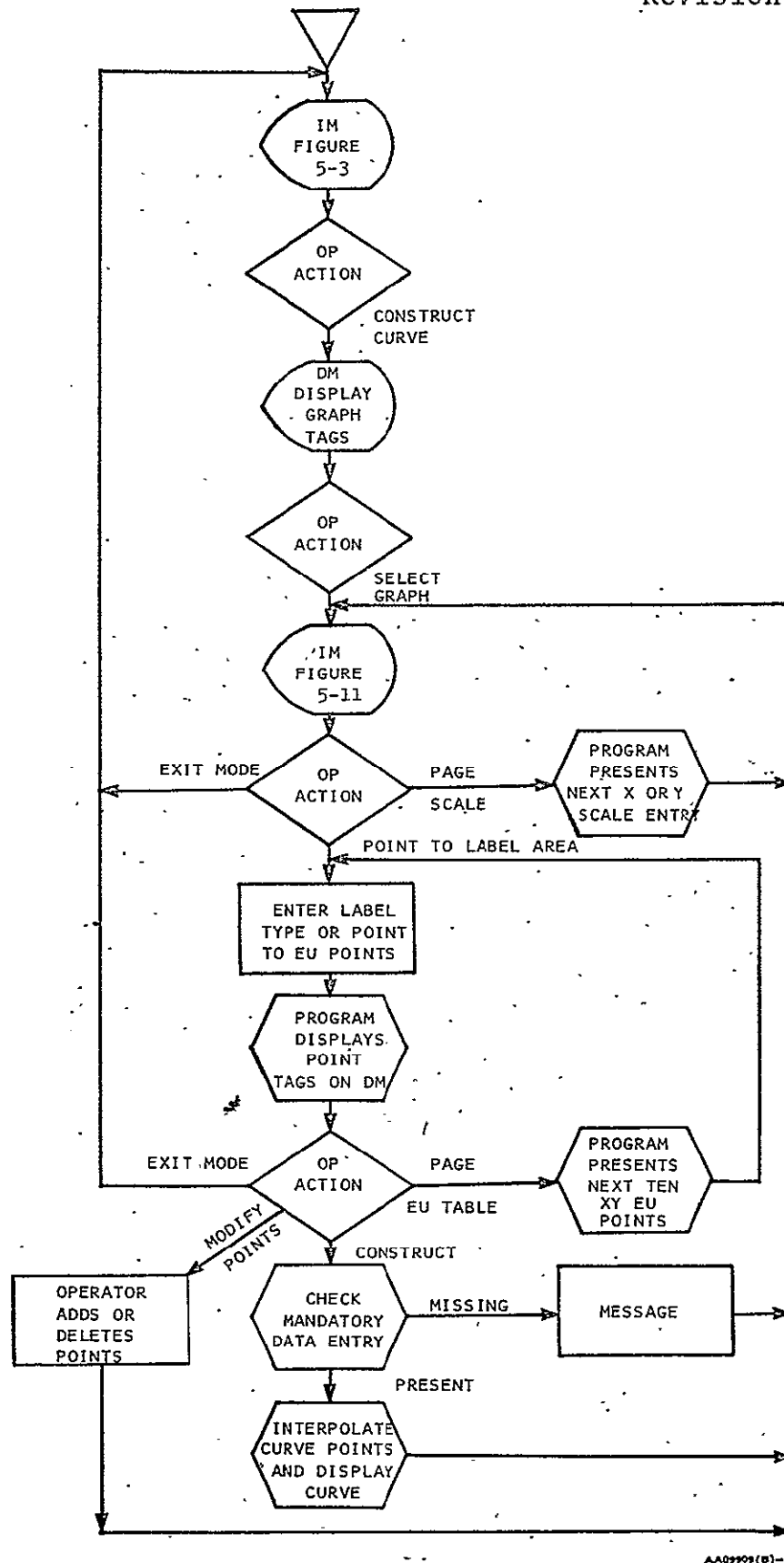
When this design option is selected, tags appear at each grid origin on the DM. Pointing to the desired grid tag erases the other tags and causes the program to present the corresponding plot FDS (Figure 5-8) on the IM. Changes, additions or deletions may then be made to the FDS data with the exception of the coordinate limits and the XY divisions.

5.2.3.5 ERASE GRAPH

When ERASE GRAPH is selected, tags appear on the DM at each grid origin. As the operator points to the grid he wishes to erase, it is deleted. Corresponding FDS entries and curve EU points are also deleted.

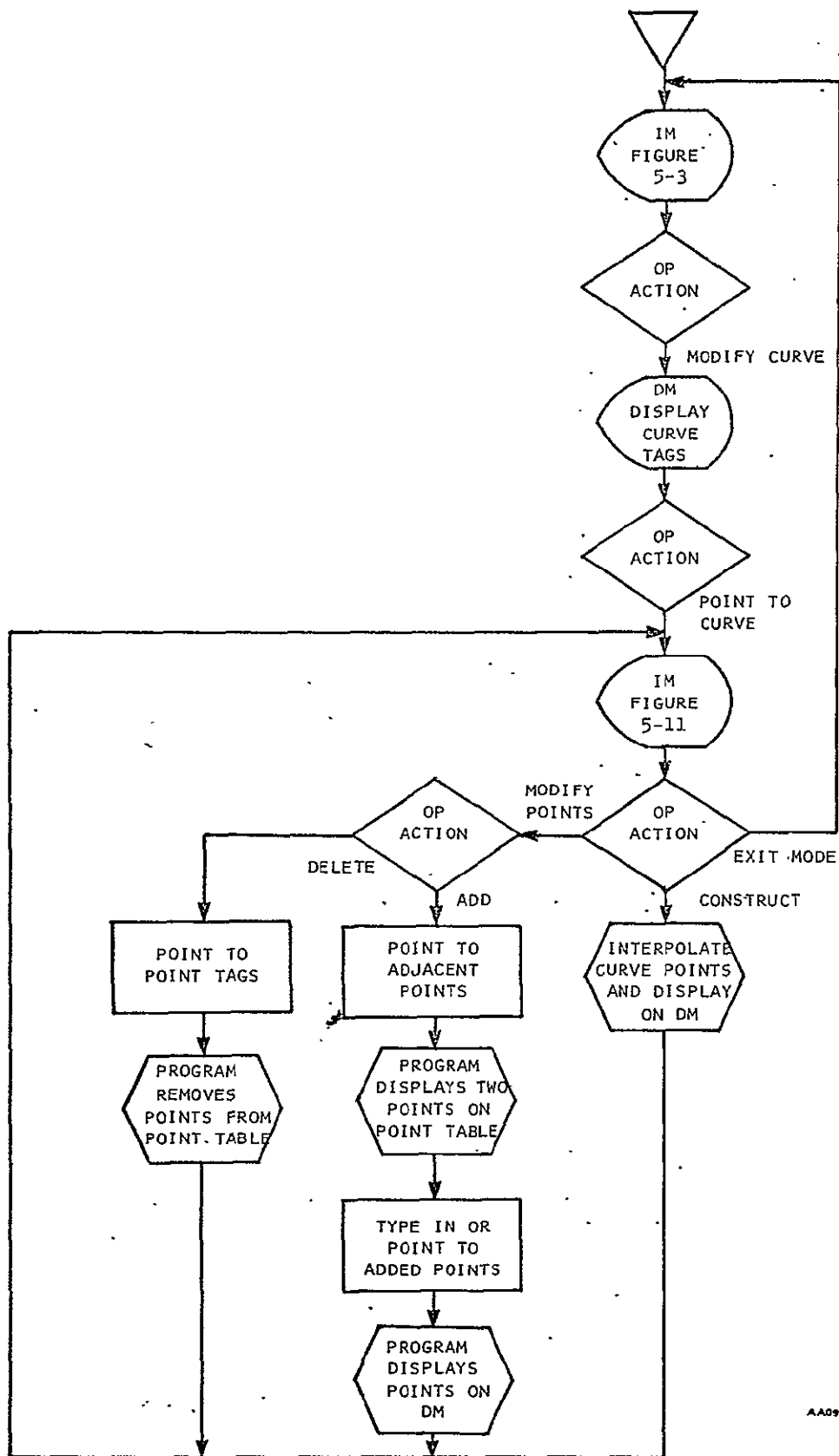
5.2.4 Curves

The construction of curves for a digital display system requires a curve fairing routine capable of interpolating intermediate points from a limited number of input points. The intermediate points and input points become the end points of line segments composing the curve. Where a number of line segments lie on a straight line, only one inclusive segment should be used in displaying the interpolated curve. Appendix A details a method of smooth curve fairing suitable for use with a digital display system. The following paragraphs and Figures 5-9 and 5-10 outline the operator/program interaction desired in creating such curves on the display screen. Note that MODIFY CURVE requires the storage and recall of each input point EU value. The curve routines require previous entry of grid data and scale data.



AA09909(B)-6

Figure 5-9 CONSTRUCT CURVE



AA09909(B)-7

Figure 5-10 MODIFY CURVE

5.2.4.1 CONSTRUCT CURVE

A. ACTION: Point to CONSTRUCT CURVE (Figures 5-3 and 5-9).

RESPONSE: Tags appear at the grid origin of each graph on the DM. The operator then selects the graph which his curve is to be plotted against.

B. ACTION: Point to tag of graph desired (Figure 5-3).

RESPONSE: The program presents the FDS data entries for that graph (Figure 5-11). Graph tags that are not selected disappear.

C. ACTION: Page X and Y scale data until the desired EU limits are displayed (Figure 5-11).

RESPONSE: The program presents consecutive scale entries for viewing.

D. ACTION: Type in the CURVE LABEL (Figure 5-11).

RESPONSE: If the operator enters the curve label, the curve is a solid line. If the operator also enters a symbol (SYM) and size (SIZ), the curve consists of a series of those symbols along the curve locus, separated by the specified interval. Interval is defined as the distance between symbol placement coordinates. The operator must enter the number of points to be interpolated in the # PTS box. The INV box provides for identifying curves having inverse functions.

E. ACTION: Type in or point to the XEU, YEU points (Figure 5-11).

D/TV X 0000		SIZE 0		DTE X 0000	
COORD Y 0000				COORD Y 0000	
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY
EXT INPUT					
◊	◊	◊	◊	◊	◊
PLOT FDS		X-AXIS		Y-AXIS	
GRID	COORD MIN	0000		0000	
DATA	COORD MAX	0000		0000	
	DIVISIONS	000		000	
SCALE	EU MIN	0000000000000000		0000000000000000	
DATA	EU MAX	0000000000000000		0000000000000000	
	SCALE #	0	◊ PAGE UP	0	◊ PAGE UP
			◊ PAGE DN		◊ PAGE DN
CURVE DATA*		EU POINT TABLE		-P-	
LABEL 000000000000		0000000000000000		0000000000000000	
00	0	0	000	0	
INT	SYM	SIZE	#PTS	INV	
CONSTRUCT		◊			
ADD		◊			
DELETE		◊			
PAGE FWD		◊			
PAGE BCK		◊			
EXIT MODE		◊			

Figure 5-11 Curve Data Display

RESPONSE: The program accesses the previously entered data for grid coordinate limits and EU scale limits. It then computes the correct coordinate position for the EU points and displays a tag at those locations on the DM. The letter "P" must be typed in after each XY pair that is a partition point. A capability for 50 XY points must be provided. Paging forward or backward provides for adding points 10 at a time. If the XY points are selected by pointing, the program enters the EU points in the EU POINT TABLE on the IM (Figure 5-11).

F. ACTION: Point to CONSTRUCT (Figure 5-11).

RESPONSE: The program checks for entry of all mandatory curve data. If data has not been entered, a message CHECK ALL DATA ENTRIES is added to IM and the operator must enter the correct information. If the data is entered correctly, the program calculates the intermediate points required for a smooth curve. Tags are not displayed for intermediate points.

If the curve is to be a solid line, vectors are displayed between the intermediate points and if the curve is to be constructed of symbols, the program displays the specified symbol at the specific interval along the curve path. When the smooth curve is fully presented on the DM, the EU point tags are removed. EXIT MODE may then be selected or additions and deletions may be made to the curve modifying its appearance.

5.2.4.2 MODIFY CURVE

A. ACTION: Point to MODIFY CURVE (Figures 5-3 and 5-10).

RESPONSE: The program places tags on each original EU point of each curve on the DM.

B. ACTION: Point to a tag on the curve to be modified.

RESPONSE: IM (Figure 5-11) is presented. The program erases tags of other curves on the DM and leaves tags on each of the original EU points specified for that curve.

C. ACTION: Point to ADD. Then point to the first of two adjacent points on the DM where additional points are to be added.

RESPONSE: Program places the XEU, YEU value of the selected point at the top of the table and the next EU point at the bottom of the EU point table. A maximum of eight additional XY EU points may then be entered by pointing or typing between the two points. After each EU point is typed or pointed to, the program will display a tag at that point on the DM.

D. ACTION: Point to CONSTRUCT (Figure 5-11).

RESPONSE: The program checks for complete entry of curve data and EU points. Intermediate points are calculated, the interpolated curve is presented on the DM, and the program returns to the IM. EXIT MODE may then be selected or further modifications may be made to the curve.

E. ACTION: Point to DELETE (Figure 5-11).

RESPONSE: After each tag is pointed to, it is erased from the screen and the EU point table. CONSTRUCT is then selected, the program smooths the curve on the DM, displays it, and returns to the IM.

5.2.4.3 ERASE CURVE

A. ACTION: Point to ERASE CURVE (Figure 5-3).

RESPONSE: The program displays tags on the first point of each curve on the DM.

B. ACTION: Point to any tag on the curve to be erased.

RESPONSE: The program erases the indicated curve from the DM and storage.

5.2.5 Entities

The entity capability provides for construction and manipulation as a unit of any number or combination of alpha groups, dynamic data symbol groups, line combinations, graphs, or curves. The entity may be moved, copied, erased, combined or its individual groups modified. An entity may also be stored, recalled, or deleted from the entity library. Selection of END ENTITY terminates the construction or modification.

5.2.5.1 CONSTRUCT ENTITY

The operator points to CONSTRUCT ENTITY to indicate that the following constructions are to be considered part of an entity. The tag for the first alpha/dynamic data group, line, graph or curve shall be overlaid with a box symbol to indicate that it is an entity pickup or tag point. Construction of the entity is accomplished with the alpha/dynamic data, line, graph and curve design functions. Pointing to END ENTITY terminates the entity construction.

5.2.5.2 MOVE ENTITY

When this option is selected, box tags appear on each entity. The homing option is presented and must be indicated.

The operator points to the entity to be moved and then to the new position desired. The program moves the entity to the new location. A series of moves of the same entity may be made without reselecting the MOVE option. Another entity may be moved by returning and pointing again to MOVE ENTITY. If one or more groups of symbols are contained within a moved entity, the associated XY coordinates of each are updated in storage.

7

5.2.5.3 COPY ENTITY

This option operates the same as MOVE ENTITY, but the original entity is not erased. If there are dynamic data groups or graphs within the entity; the appropriate FDS is presented on the IM allowing the addition or modification of the descriptive data.

5.2.5.4 MODIFY ENTITY

When this option is selected, tags appear at the beginning of all entities. The following display is added to the IM and the operator selects MODIFY or COMBINE.

ENTITY		
o	MODIFY	o
	COMBINE	

COMBINE provides for the combination of each subsequent entity indicated with the first selected. Selection of MODIFY allows internal modification of the first entity pointed to. After choosing to MODIFY an entity, the operator proceeds with modification by selecting the desired alpha, line, graph, or curve options. The modification or combination is terminated with END ENTITY since, in effect, a new entity has been constructed. If the original entities are stored, this action does not alter their configuration in the entity library.

5.2.5.5 ERASE ENTITY

The selection of this option places tags at the beginning points of all entities that are displayed on the DM. The operator points to the entity to be erased, but erasing the entity from the DM does not remove it from the entity library.

5.2.5.6 STORE ENTITY

When this option is selected, tags appear at the starting points of all entities on the DM. The following display is added to the IM.

①

ID NUMBER	ENTITY NAME	OPERATOR	DATE

The operator types in the ID number, the entity name, his name or initials, and the date. When the operator enters the number, the program will store the entity at the specified number and enter that number in the entity TOC. If the operator does not enter an ID number, the program will store the entity at the lowest available open number and enter that number in the entity library TOC.

The operator then points to the entity to be stored. In the event sufficient storage is not available, the message YOU HAVE EXCEEDED ENTITY LIBRARY STORAGE will be added to Figure 5-3 on the IM. The operator may then review and delete unused entities from the entity library.

5.2.5.7 CALL ENTITY

A. ACTION: Point to CALL ENTITY (Figure 5-3 and Figure 5-12).

RESPONSE: The following display is added to the IM to provide the operator the option of viewing the Table of Contents.

DO YOU WANT TO SEE THE TOC

YES ☐

NO ☐

B. ACTION: Point to NO on TOC viewing option.

(2) (4)

RESPONSE: The program adds the message TYPE IN ENTITY ID NUMBER.

After the operator types in the entity ID number the program adds the following display to the IM allowing the operator to select a homing option.

SELECT CHARACTER SIZE ON ANK, THEN

SELECT HOMING OR TYPE IN COORDINATES.

CHARACTER ☐ COORDINATE ☐ STORED ☐

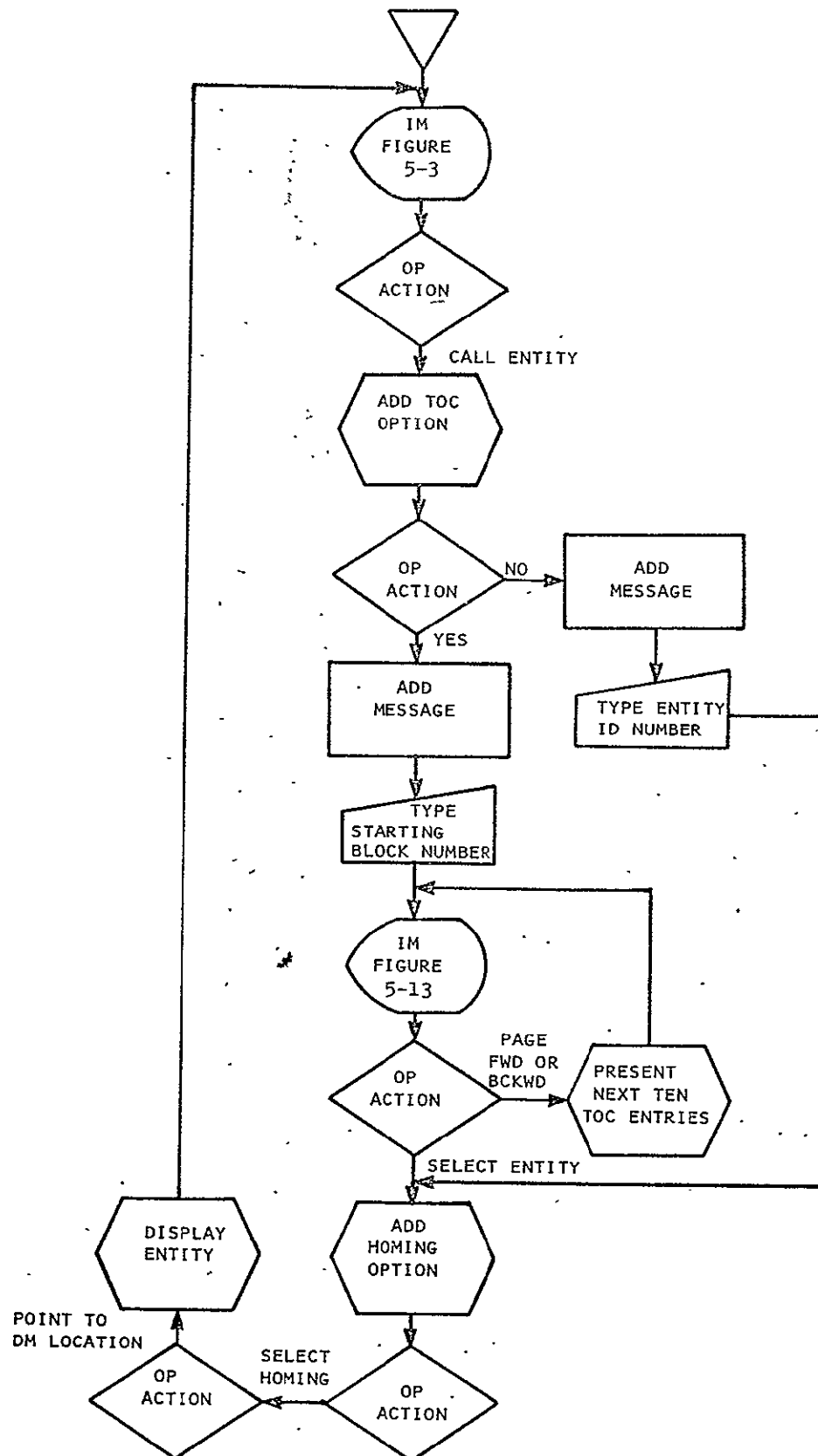


Figure 5-12 CALL ENTITY

C. ACTION: Point to YES on TOC viewing option.

(10)

RESPONSE: The program adds the message TYPE IN STARTING BLOCK NUMBER. After the operator types in a starting block number the program presents Figure 5-13 with ten TOC entries. A paging option provides for selection of the ten following or preceding entries. The operator may then select the desired entity by pointing to corresponding selection boxes.

D. ACTION: Point to the selection box for the desired entity (Figure 5-13).

RESPONSE: The program adds the above homing option display to the IM allowing the operator to indicate how he wants to locate the entity on the DM.

E. ACTION: Point to desired homing option and then point to DM location for entity.

RESPONSE: The program calls and displays the entity at the DM location pointed to according to the homing option selected. Note that when STORED homing is selected, the operator may point to any DM location as the entity will be recalled at its stored location. After the entity is displayed the program returns the operator to IM (Figure 5-3).

5.2.5.8 DELETE ENTITY

The sequence of operations here is identical to that of CALL ENTITY. After the TOC is presented and the entity is called and displayed on the DM, the following display is added to Figure 5-3 on the IM.

DELETE ENTITY			
<input type="radio"/>	YES	NO	<input type="radio"/>

This forces the operator to view the entity before deletion from the entity library is completed. Deletion of the entity occurs in both the entity library and entity TOC when YES is selected.

D/TV X
 COORD Y

SIZE

DTE X
 COORD Y

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

ID #	ENTITY NAME	OPERATOR	DATE
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

PAGE: FORWARD ☐ BACKWARD ☐

Figure 5-13 Entity TOC Display

5.3 SAVE DISPLAY

This option provides for saving a display with a new MSK/FCN/PCL or saving a modified display with the same MSK/FCN/PCL. Checks are provided to prevent storing the same display twice or writing over an existing display unintentionally. Figure 5-14 and the following paragraphs outline the major functions.

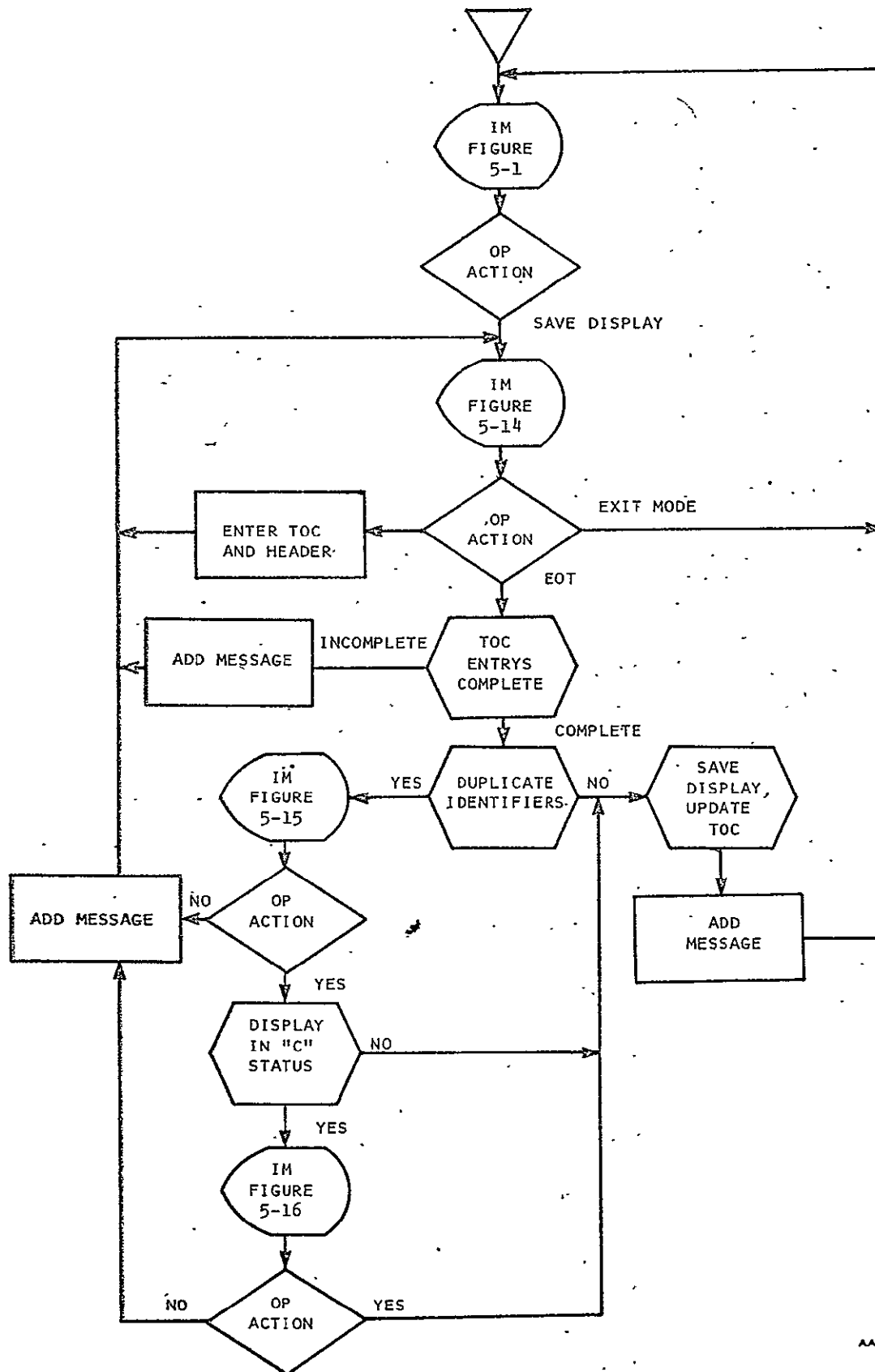
A. ACTION: Point to SAVE DISPLAY (Figure 5-1).

RESPONSE: The TOC box and display header information are displayed (Figure 5-15). If the display is new, the TOC box and header information must be filled in. If it is an old display, the previously entered data is displayed. Data may be entered, deleted or changed from the ANK.

B. ACTION: Strike EOT key (Figure 5-15).

RESPONSE: The program checks for completion of the MSK/FCN/PCL, type and mission entries in the TOC block. If these entries are not complete, the program adds the message MORE TOC IDENTIFICATION REQUIRED to the IM (Figure 5-15). Identification must be completed before the program can continue. If TOC entries are complete, the program searches the TOC file for a duplicate MSK/FCN/PCL entry. If a duplicate entry is found, the program replaces the header information with Figure 5-16, thus requiring the operator to make a decision to overlay and destroy the existing display in the library and to reidentify the display on the DM. If a duplicate entry is not found, the program saves the display in the display library and enters the MSK/FCN/PCL identifier in the TOC at the proper location. The message DISPLAY SAVED will be returned to IM (Figure 5-1).

C. ACTION: Point to NO (Figure 5-16).



AA09909(B)-8

Figure 5-14 SAVE DISPLAY

D/TV X 0000		SIZE 0		DTE X 0000		
COORD Y 0000				COORD Y 0000		
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
◇	◇	◇	◇	◇	◇	◇

DISPLAY			TOC	ENTRY	
MSK	FCN	PCL	STATUS	TYPE	MISSIONS
0000	0000	0	0	0000	00000,00000,00000

```
DRK TITLE *****  
TITLE ****  
SMEK 00 SIZE 0 FDSC 00  
UPDATE RATE 0000 SUNFLOWER 000,000,000  
AGC-PWR 0 RNDZ 0 COAST 0 UPDATE 0 PG22 0  
LGC-PWR 0 RNDZ 0 COAST 0 UPDATE 0 D/AS 0  
LUNAR ALIGN 0  
COMMENTS*****  
*****  
*****  
*****  
*****  
*****  
*****  
***** EXIT MODE
```

Figure 5-15 TOC and Header Display

D/TV X 0000		SIZE <input type="checkbox"/>		DTE X 0000	
COORD Y 0000				COORD Y 0000	

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
◊	◊	◊	◊	◊	◊	◊

DISPLAY TOC ENTRY					
MSK	FCN	PCL	STATUS	TYPE	MISSIONS
0000	0000	0	0	0000	00000,00000,00000

A DISPLAY WITH THIS MSK/FCN/PCL IS ALREADY IN THE LIBRARY. DO YOU WISH TO OVERLAY AND DESTROY IT?	
◊ YES	NO ◊

Figure 5-16 Overlay Message Display

RESPONSE: The program returns the message DIFFERENT TOC IDENTIFICATION REQUIRED to the IM (Figure 5-15). This provides the operator with the option of reidentifying the display and saving it under another MSK/FCN/PCL identifier.

D. ACTION: Point to YES (Figure 5-16).

RESPONSE: The program checks the TOC status area of the display in the library for a "C" indicating completion. If a "C" is not found in the TOC status area of the display in storage, the program saves the display shown on the DM by overlaying the display in storage. The message DISPLAY SAVED is returned to IM (Figure 5-1).

If a "C" is present in the TOC status area of the display in storage, Figure 5-17 replaces the header information and the operator makes a positive decision to overlay and delete.

E. ACTION: Point to YES (Figure 5-17).

RESPONSE: The program saves the display on the DM by overwriting the display in storage. The message DISPLAY SAVED is returned to IM (Figure 5-1).

F. ACTION: Point to NO (Figure 5-17).

RESPONSE: The program adds the message DIFFERENT TOC IDENTIFICATION REQUIRED to IM (Figure 5-15). This provides the option of reidentifying the display and saving under another MSK/FCN/PCL identifier.

G. ACTION: Point to EXIT MODE (Figure 5-15).

RESPONSE: The program returns the operator to Figure 5-1. This option allows entry of TOC and header information without immediately saving the display.

D/TV X 0000		SIZE 0		DTE X 0000	
COORD Y 0000				COORD Y 0000	

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
0	0	0	0	0	0	0

DISPLAY TOC ENTRY					
MSK	FCN	PCL	STATUS	TYPE	MISSIONS
0000	0000	0	0	0000	000000.000000.000000

THIS DISPLAY HAS BEEN COMPLETED. DO YOU HAVE AUTHORIZATION TO DELETE?			
0	YES	NO	0

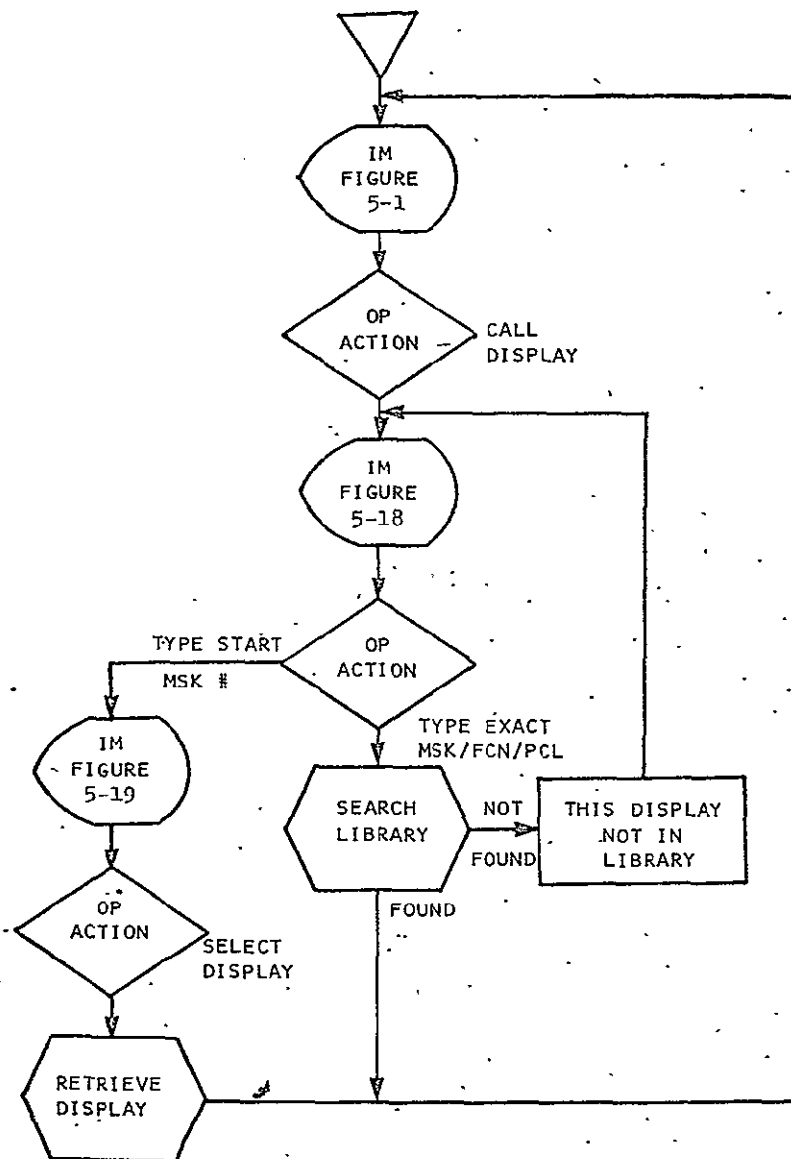
Figure 5-17 Deletion Authority Message

5.4 CALL DISPLAY

12

This option provides for calling any individual display in the DRAFT display library through a series of IM matrix selections. An alternative calling capability provides for keyboard entry of the exact MSK/FCN/PCL identifier.

- A. ACTION: Point to CALL DISPLAY (Figures 5-1 and 5-18).
- RESPONSE: The TOC entry block display appears (Figure 5-19).
- B. ACTION: Type in exact MSK/PCL/FCN identifiers followed by EOT. (Figure 5-19)
- RESPONSE: The display library TOC is searched. If the display is in the library, the display appears on the DM while the stored status, type and mission information appears on the IM. If the display is not found, the message THIS DISPLAY NOT IN LIBRARY is returned to the IM (Figure 5-19) and the operator must reselect CALL DISPLAY.
- C. ACTION: Type in MSK number only, followed by EOT (Figure 5-19).
- RESPONSE: The display library is searched for the first entry with that MSK number. A TOC page with that entry and the next succeeding nine entries are presented on Figure 5-20. A paging option provides for paging forward or backward from that point in the TOC.
- D. ACTION: Point to TOC selection box for desired display (Figure 5-20).
- RESPONSE: The program retrieves the display from the library and presents it on the DM. The stored status, type and mission information is displayed on Figure 5-19.



AA09904(B)-9

Figure 5-18 CALL DISPLAY

D/TV X 0000		SIZE 0		DTE X 0000	
COORD Y 0000				COORD Y 0000	

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
0	0	0	0	0	0	0

DISPLAY TOC ENTRY					
MSK	FCN	PCL	STATUS	TYPE	MISSIONS
0000	0000	0	0	0000	00000.00000.00000

Figure 5-19 TOC Entry Block

D/TV X 0000		SIZE 0		DTE X 0000	
COORD Y 0000				COORD Y 0000	
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY
◇	◇	◇	◇	◇	◇

	DISPLAY				TOC	
	MSK	FCN	PCL	STATUS	TYPE	MISSIONS
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000
◇	0000	0000	0	0	0000	00000,00000,00000

PAGE: FORWARD 0 BACKWARD 0

Figure 5-20 TOC Display

5.5 OUTPUT EXTERNAL

This option provides for output from the display library of listings, seven and nine track tapes, and a diskpack. Listing from diskpack tracks is also provided. Figure 5-21 shows output selections available. Combinations of a display, display range, mission, mission range, track and track range may be selected by typing in the identification in the proper format and ending with EOT. Output of a complete file is selected by typing DUMP.

5.5.1 TOC Lists

The "Table of Contents" list shall be an 80-column list containing the following items: MSK number, FCN, PCL, DRK title, type of display, mission identification, and completion status. Options for combinations of displays and display ranges with missions and mission ranges will be available. DUMP lists the complete TOC file.

5.5.2 FDS Lists

The FDS list is an 80-column list of the header information and line item entries for each dynamic data group on a display. Options are provided for specifying (by MSK) an individual display or range of displays in combination with a mission or mission range. DUMP lists the complete FDS for all displays in the library. The listing format should be as specified in PHO-TR147, *Display Formats Manual*, Revision C, Change 3.

- A. Limit Sense Diamond* When the limit sense diamond (DTE Octal Code 207) is included in a dynamic data group, it will be ignored by the routine outputting the FDS tape or listing. The diamond never appears in the format field section of an FDS output.
- B. Coordinates Field. FDS outputs are normally left-adjusted; however, right adjusted 1024 x 1024 X coordinates are given for displays with the following entries under TYPE in the TOC: TAB1, TAB2, TAB3, TAB4, TAB5, and PLT2. All dynamic data coordinates are stored left-adjusted; therefore, the output routine must make the proper adjustment.

D/TV X 0000 SIZE 0 DTE X 0000
COORD Y 0000 COORD Y 0000

DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY	EXT INPUT
◊	◊	◊	◊	◊	◊	◊

TOC LIST	FDS LIST	FDS TAPE	GERBER TAPE	BCKGRND TAPE	CONST MD	LIST MD
◊	◊	◊	◊	◊	◊	◊

DISPLAY XXXX. DISPLAY RANGE XXXX,XXXX.
MISSION XXXXX. MISSION RANGE XXXXX,XXXXX.
TRACK X/XXX. TRACK RANGE X/XXX,X/XXX.
TYPE ID NUMBERS IN ONE OF ABOVE FORMATS - THEN EOT.

Figure 5-21 Output External Display

- C. MR Code in Format Field. When the MR code appears in a dynamic data group, it is interpreted on output as a slash (/). When the margin return slash appears within right-adjusted displays, the X coordinate output is that of the symbol preceding the first MR slash.
- D. Curve EU Points. Displays with static data curves include the stored XEU and YEU values. These values are appended to the FDS listing for the display, but they are not included in the FDS tape output. Each set of curve EU values is preceded by its curve ID and the interval, symbol and size if present. A separate line should be used in printing each set of XEU, YEU point values.
- E. Total Bytes. This is an output program entry of the total number of FDS data bytes for the display.
- F. Total Dynamic Data Characters. This is an output program entry of the total number of dynamic data alphanumeric characters on the display. The number appears at the end of the FDS listing output for each display.

5.5.3 Gerber Language Tape

The Gerber Language Tape is a seven-track numerical control tape to be used on the Gerber automatic drafting machine. It consists of the background information for a display or range of displays, plus the Fiducial alignment marks common to all slide formats. Options provide for a single display or range of displays in combination with a mission or range of missions. A listing of the TOC information for each display on the tape is printed simultaneously with the Gerber tape production. A capability to write a series of displays to the same tape without prior storage in the display library is required.

5.5.4 RTCC Background Tape

⑬

The RTCC Background Tape is as described in the NASA letter listed in the references (Paragraph 1.4). A single mission is output including only those displays having a "C" in the status area.

The output program counts the total number of computer language words written to the tape for each display and presents an error message when the total exceeds 1536.

5.5.5 FDS Tape

(13)

The FDS tape contains the same information as the FDS listing with the exception of EU curve values. The FDS output format is specified in PHO-TR147, *Display Formats Manual*, Revision C, Change 3. Output of one mission at a time is required.

5.5.6 DTE Mission Diskpack

(13)

The Mission Diskpack (MD) conforms to the specification set forth in the *DTE Background Disk Recording Program Requirements*, PHO-TR446. Output of a single mission, including only those displays in the "C" status, is required. The MSK/track conversion table is constructed as displays are assigned to the Mission Diskpack tracks.

The output program counts the total number of computer language words written to the disk for each display and presents an error message when the total exceeds 1536.

5.5.7 Selected MD Listings

(13)

This option provides for listing individual Mission Diskpack tracks or a range of tracks on the complete diskpack. The track ID is a head number (0 thru 9) followed by a slash and the cylinder number (0 thru 202).

5.6 DELETE DISPLAY

(11)

This selection provides for removing a display from the display library. When DELETE DISPLAY is selected, Figure 5-19 is presented and operation proceeds exactly as in CALL DISPLAY until the display is presented on the DM. At that point, the following display is added to Figure 5-19 and the operator must indicate a yes or no decision to delete. The additional step provides the operator an opportunity to view the display and the TOC entries for status and mission prior to deletion.

DELETE DISPLAY

YES ☐ NO ☐

5.7 DM ERASE

Selection of DM ERASE provides for clearing of the DM and the computer work area. The following display is added to Figure 5-1 as a double check against accidental erasure. Selection of YES completes clearance of the DM.

ERASE DISPLAY MONITOR			
<input type="checkbox"/>	YES	NO	<input type="checkbox"/>

5.8 INPUT EXTERNAL

(14)

This option provides for tape input of displays, the character font (dot matrix) table, the coordinate conversion table, and the DTE diagnostic routines. A capability for maintaining and updating these is required. Figure 5-22 appears on the screen and provides for selection of an input data type.

5.8.1 Display Library Input

(14)

Selection of this option causes the program to read the tape and present the first display read on the DM. The operator may select one of the major options and proceed to SAVE, DELETE, or MODIFY. Typical displays consist of header information (MSK, FCN, PCL, status, mission) followed by DTE data words in symbolic form.

D/TV X 0000		SIZE 0		DTE X ^ 0000	
COORD Y 0000				COORD Y 0000	
DM ERASE	DELETE DISPLAY	DISPLAY DESIGN	CALL DISPLAY	OUTPUT EXT	SAVE DISPLAY
◊	◊	◊	◊	◊	◊

DISPLAY LIBRARY	DIAG ROUTINE	CHAR FONT	COORD CONV
◊	◊	◊	◊

Figure 5-22 External Input Display

(Reference SP-08873A, Paragraph 3.2.2.1.2,C.) The character coordinates are those of the character box center. Appendix C specifies symbolic card image formats and symbol library codes.

5.8.2 DTE Diagnostic Routines

⑭

Selection of this input causes the program to read the diagnostic data from the tape. Display data words are placed on the screen for viewing and an option to select the DTE Diskpack cylinder and head destination is presented. The operator must enter them from the keyboard. The diagnostic data is then stored on the working diskpack ready for output to the DTE Diskpack. A capability for processing 36-bit and 48-bit word formats in symbolic form is required. Appendix C specifies the required symbolic formats.

5.8.3 Character Font Table

⑭

Selection of this option causes the program to read the character font (dot matrix) table from the tape and store it on the working disk for later output to the DTE Diskpack. PHO-TR446 specifies the exact format required.

5.8.4 Coordinate Conversion Table

⑭

Selection of this option causes the program to read the coordinate conversion table from the tape and store it on the working disk for later output to the DTE Diskpack. The format is specified in PHO-TR446.

APPENDIX A

SURVEY OF APPLICABLE SMOOTH CURVE FAIRING TECHNIQUES

A.1 GENERAL.

The purpose of the Smooth Curve Fairing (SCF) Operation is to interpolate within an initial point set such that vectors generated for successive point pairs approximate a smooth curve.

The techniques for locating intermediate points on a smooth curve through a given set of points can be classified into mechanical drawing techniques and mathematical techniques. Mathematical techniques can be further distinguished as being (1) interpolating methods which define a curve which passes through all the given points and (2) as being data smoothing techniques which fit a predetermined function to a large number of points in such a manner as to minimize error expression.

A.2 MECHANICAL DRAWING TECHNIQUES

Drafting makes use of mechanical guides to develop smooth lines through a set of points. Rulers and triangles are used to connect points lying in a straight line. Non-colinear points can be connected by compass, ellipse drawing machines, or with irregular (French) curves. Use of the compass is usually restricted to a small number of points or to point sets that do not represent changes of sign for curvature radii. Ellipse drawing machines, even more specialized than the compass, are usually restricted to depicting tilted projections of circles.

By far the most versatile instruments for connecting a set of non-colinear points with a smooth line are the irregular, or so-called French, curves. Irregular curves are curved ruling guides made up of successive portions of conics (ellipses, parabolas, hyperbolas) with portions of ellipses being the most useful forms. Some irregular curves, such as ships curves, are made up of portions of non-conics such as spirals. In use the irregular curve is matched to as much of the line as it will conveniently fit, and a solid line is drawn using the irregular curve as a guide.

It may be necessary to use several portions of the irregular curve to produce the desired line because of changes in curvature. It is important that each section be a continuation of the section previously drawn so the finished curve will be free from undesired bumps or irregularities. This continuation is achieved by the practice of "overfitting and under-drawing", i.e., the irregular curve is arranged so that a portion passes through a maximum number of points, starting from the end of the last portion of the curve drawn. The curve is extended without connecting the last point, or last two points, which still fit the irregular curve. This process is repeated using the same French curve, or alternate curves when necessary, to yield the best looking curve.

A.3 INTERPOLATION METHODS

Interpolation methods make use of an interpolation formula or function which attains the same values as the given ordinates for the given abscissas. Interpolation is the process of replacing a function by another function that can, for practical purposes, be used in its stead.

The given points are assumed from a relation that represents a continuous piecewise-smooth graph in the interval of interest.. The following axiomatic basis is recalled to develop the required characteristics of acceptable interpolation equations.

- A. Definition (1) Continuity (Cauchy). It is said that a function, $f(x)$, is "continuous at the point a " if an arbitrary number ($\epsilon > 0$) is being chosen and another number ($\delta > 0$) exists such that for every x in the δ -neighborhood of point a , the relation

$$|f(x) - f(a)| < \epsilon \quad (1)$$

holds.

A great majority of functions met in applications are continuous, especially all polynomials and rational functions with non-vanishing denominators. The function $y = \sqrt{x}$ is continuous for $x \geq 0$. Trigonometric functions are continuous, except for the points in the neighborhood of which they are not bounded. (For example, the function $\tan x$ is not continuous at the point $\pi/2$.) Inverse trigonometry functions, exponential functions, logarithmic functions, and functions generated from them by addition, subtraction, multiplication and division (with non-vanishing divisors), as well as their composite functions, are also continuous.

- B. Definition (2) Smoothness. A function $y = f(x)$ that has a continuous derivative in $[a, b]$ is called a "smooth function in $[a, b]$." In curve $y = f(x)$, the graphical representation is also said to be smooth.

- C. Definition (3) Concavity and Convexness. If in a certain neighborhood U of the point a , the graph of the function $f(x)$ lies below the tangent (or on the tangent) drawn at the point $[a, f(a)]$ (i.e., if the relation $f(x) \leq f(a) + (x-a) f'(a)$ holds in U), it is said that $f(x)$ is "concave at the point a ." If the graph lies above the tangent (or on the tangent), (i.e., the relation $f(x) \geq f(a) + (x-a) f'(a)$ holds in U), it is said that $f(x)$ is "convex at the point a ."
- D. Definition (4) Point of Inflection. If the graph of a function crosses at the point $x = a$ and its tangent is at this point, it is said that $f(x)$ has a "point of inflection at the point a ."
- E. Theorem (1) Extrema. If $f'(a) = 0$ and $f''(a) > 0$, then $f(x)$ has a relative minimum at a ; if $f'(a) = 0$ and $f''(a) < 0$, then $f(x)$ has a relative maximum at a . If $f'(a) \neq 0$, then $f(x)$ has no relative extremum at a .
- F. Theorem (2) Zero Second and Higher Derivatives. Let $f''(a) = f'''(a) = \dots = f^{(n-1)}(a) = 0, f^{(n)}(a) \neq 0 (n \geq 2)$.
Then $f(x)$ is convex at a when $f^{(n)}(a) > 0, n$ even,
 $f(x)$ is concave at a when $f^{(n)}(a) < 0, n$ even,
 $f(x)$ has a point of inflection at (a) (and crosses the tangent from below) when $f^{(n)}(a) > 0, n$ odd, and
 $f(x)$ has a point of inflection at (a) (and crosses the tangent from below) when $f^{(n)}(a) < 0, n$ odd.
- G. Theorem (3) Zero First and Higher Derivatives. Let $f'(a) = f''(a) = \dots = f^{(n-1)}(a) = 0, f^{(n)}(a) \neq 0 (n \geq 1)$.
Then $f(x)$ has a relative minimum at a when $f^{(n)}(a) > 0, n$ even,
 $f(x)$ has a relative maximum at a when $f^{(n)}(a) < 0, n$ even,
 $f(x)$ is increasing at a when $f^{(n)}(a) > 0, n$ odd,
 $f(x)$ is decreasing at a when $f^{(n)}(a) < 0, n$ odd.

- H. Theorem (4) Weierstrass's Theorem. It is possible to approximate uniformly in $[a, b]$ with an arbitrary accuracy every function continuous in $[a, b]$ by means of a sequence of polynomials, i.e., to every $\epsilon > 0$ there exists a polynomial $P_n(x)$ such that

$$|f(x) - P_n(x)| < \epsilon \text{ for all } x \in [a, b]. \quad (2)$$

- I. Theorem (5) Uniqueness. There is one interpolation polynomial $P_n(x)$ that attains at $(n+1)$ different points, the same values as the given function $f(x)$.

- J. Definition (5) Interpolation Formula. The equation

$$f(x) = P_n(x) + R_n(x), \quad (3)$$

where $P_n(x)$ is the interpolation polynomial and $R_n(x)$ is the remainder term, is called the interpolation formula. We write

$$f(x) \approx P_n(x). \quad (4)$$

If the arguments are not equidistant, i.e., if the difference $x_{k+1} - x_k$ is not a constant for all k , equation (3) is called the general interpolation formula.

- K. Definition (6) Divided Differences. The first divided difference (or the divided difference of the first order) is defined (for different values of the x 's) by the relation

$$f(x_\mu, x_\nu) = \frac{f(x_\mu) - f(x_\nu)}{x_\mu - x_\nu} = \frac{f(x_\mu)}{x_\mu - x_\nu} + \frac{f(x_\nu)}{x_\nu - x_\mu}, \mu \neq \nu. \quad (5)$$

The second divided difference (or the divided differences of the second order) is defined by

$$\begin{aligned} f(x_\mu, x_\nu, x_\lambda) &= \frac{f(x_\mu, x_\nu) - f(x_\nu, x_\lambda)}{x_\mu - x_\lambda} \\ &= \frac{\frac{f(x_\mu)}{x_\mu - x_\nu} + \frac{f(x_\nu)}{x_\nu - x_\mu} - \frac{f(x_\nu)}{x_\nu - x_\lambda} - \frac{f(x_\lambda)}{x_\lambda - x_\nu}}{x_\mu - x_\lambda} \end{aligned} \quad (6)$$

Similarly, the n^{th} dividend difference (or the divided difference of the n^{th} order) is defined by

$$f(x_0, x_1, x_2, \dots, x_n) = \frac{f(x_0, x_1, x_2, \dots, x_{n-1}) - f(x_1, x_2, \dots, x_n)}{x_0 - x_n}$$

$$= \sum_{i=0}^n \frac{f(x_i)}{\prod_{\substack{j=0 \\ j \neq i}}^n (x_i - x_j)} \quad (7)$$

L. Theorem (6) Argument Symmetry. Divided differences are symmetric functions of their arguments, e.g., $f(x_1, x_2, x_3)$.
 $= f(x_2, x_1, x_3) = f(x_2, x_3, x_1) = f(x_3, x_1, x_2) = f(x_3, x_2, x_1)$
 $= f(x_1, x_3, x_2).$

M. Theorem (7) Divide Differences Related to Derivatives. Let the constants $[a, b]$ be defined by

$$a = \min (x_0, x_1, \dots, x_n)$$

$$b = \max (x_0, x_1, \dots, x_n)$$

If the function $f(x)$ possesses an i^{th} derivative in the interval $[a, b]$, then the i^{th} divided difference can be expressed in terms of the i^{th} derivative at point $\xi \in [a, b]$ as follows:

$$f(x_0, x_1, \dots, x_i) = \frac{f^{(i)}(\xi)}{i!}, \quad a < \xi < b. \quad (8)$$

N. Definition (7) Limits of Divided Differences. If $x_\mu = x_\nu$, we define

$$f(x_\nu, x_\nu) = \lim_{x_\mu \rightarrow x_\nu} \frac{f(x_\mu) - f(x_\nu)}{x_\mu - x_\nu} = f'(x_\nu) \quad (9)$$

If $x_0 = x_1 = \dots = x_v$, we define

$$\underbrace{f(x_v, x_v, \dots, x_v)}_{(i+1) \text{ - times}} = \frac{1}{i!} f^{(i)}(x_v). \quad (10)$$

It can be seen that given the $(n+2)$ points on a curve: $[x, f(x)]$, $[x_0, f(x_0)]$, $[x_1, f(x_1)]$, $[x_2, f(x_2)]$, ..., $[x_n, f(x_n)]$, where the x_i , ($i = 0, 1, 2, \dots, n$) are specified abscissas and $[x, f(x)]$ is a general point anywhere on the curve, then the $(n+1)^{\text{st}}$ differences can be expressed as

$$f(x, x_0, x_1, \dots, x_n) = \frac{f(x)}{\prod_{i=0}^n (x - x_i)} + \sum_{i=0}^n \left[\frac{f(x_i)}{(x_i - x)} \frac{1}{\prod_{\substack{j=0 \\ j \neq i}}^n (x_i - x_j)} \right] \quad (11)$$

Solving equation (11) for $f(x)$, we have

$$f(x) = \sum_{i=0}^n f(x_i) \prod_{\substack{j=0 \\ j \neq i}}^n \left[\frac{(x - x_j)}{(x_i - x_j)} \right] + f(x, x_0, x_1, \dots, x_n) \prod_{i=0}^n (x - x_i). \quad (12)$$

It can be seen that the summation term on the right side is an n^{th} order polynomial that attains at the $n+1$ given abscissas the same ordinate values as for the given points. From Theorems (4) and (5) it is obvious that

$$P_n(x) = \sum_{i=0}^n f(x_i) \prod_{\substack{j=0 \\ j \neq i}}^n \left[\frac{(x - x_j)}{(x_i - x_j)} \right] \quad (13)$$

and from equation (3),

$$R_n(x) = f(x, x_1, x_2, \dots, x_n) \prod_{i=0}^n (x - x_i). \quad (14)$$

Formula (13) is called the Lagrange interpolation polynomial and formula (12) is the Lagrange interpolation formula.

If $f(x)$ possesses an $(n+1)^{st}$ derivative in the interval $[a, b]$, then from equations (10) and (14) we have the inequality

$$|R_n| \leq \frac{1}{(n+1)!} \max |f^{(n+1)}(\xi)| \prod_{i=0}^n (x - x_i), \quad \xi \in [a, b] \quad (15)$$

which is the upper bound for the error magnitude between $f(x)$ and $P_n(x)$ in the interval $[a, b]$.

The terms in equation (13) can be regrouped so that $P_n(x)$ is expressed as

$$P_n(x) = f(x_0) + \sum_{i=1}^n \left[f(x_0, x_1, \dots, x_i) \prod_{j=1}^{i-1} (x - x_j) \right] \quad (16)$$

so that from equation (3) and (16)

$$f(x) = f(x_0) + \sum_{i=1}^n \left[f(x_0, x_1, \dots, x_i) \prod_{j=1}^{i-1} (x - x_j) \right] + R_n(x). \quad (17)$$

Equation (16) is called the Newton general interpolation polynomial and equation (17) is called the Newton general interpolation formula.

Other regroupings of equations (12) and (17), under less general assumptions, obtain other formulas associated with the name of Gregory, Gauss, Stirling, Bessel, Everett, Steffensen, Comrie and Neville. These formulas are expressed in terms of function values or differences. The former is called the Lagrangean form. Numerically the two forms are exactly equivalent.

If theorem (7) is applied to equation (17), the divided differences in equation (17) take the form of equation (10). If

$$(x - x_j) \rightarrow (x - x_0) \text{ for all } j,$$

then

$$f(x) = f(x_0) + \sum_{i=1}^n (x - x_0)^i \frac{f^{(i)}(x_0)}{i!} + R_n(x) \quad (18)$$

where

$$R_n(x) = \frac{(x - x_0)^{n+1}}{(n+1)!} f^{(n+1)}(\xi), \quad \begin{cases} x_0 < \xi < x \text{ for } x > x_0 \\ x < \xi < x_0 \text{ for } x < x_0 \end{cases} \quad (19)$$

Formula (18) is known as Taylor's formula with remainder. This formulation assumes the existence of continuous derivatives up to and including order $(n+1)$ in some interval for which x_0 and x are inside points. If $f(x)$ is analytic, i.e., $f^{(n)}(x)$ exists for all n , then $f(x)$ can be expressed as the infinite series from equation (18):

$$f(x) = f(x_0) + \sum_{i=1}^{\infty} (x - x_0)^i \frac{f^{(i)}(x_0)}{i!} \quad (20)$$

Formula (20) is called an "expansion about the point x_0 of the function $f(x)$ into an infinite Taylor power series." For the special case where $x_0 = 0$, we obtain from equation (18)

$$f(x) = f(0) + \sum_{i=1}^n x^i \frac{f^{(i)}(0)}{i!} + R_n(x) \quad (21)$$

where

$$R_n(x) = \frac{x^{n+1}}{(n+1)!} f^{(n+1)}(\xi), \quad \begin{cases} 0 < \xi < x \text{ for } x > 0 \\ x < \xi < 0 \text{ for } x < 0 \end{cases} \quad (22)$$

Equation (21) is called Machlaurin's formula with remainder.

Again for a function analytic at $x = 0$, $f(x)$ can be expressed as the infinite series.

$$f(x) = f(0) + \sum_{i=1}^{\infty} x^i \frac{f^{(i)}(0)}{i!} \quad (23)$$

Equation (23) is called Maclaurin's series.

Equations (18), (20), (21), and (23) are not interpolation formulas since these are expansions about a single point. However, they serve to introduce the concept that derivatives may be used to solve for general equations with a greater number of degrees of freedom (or unknown parameters) than the number of given points. This will be shown presently.

Given that it is desired to find the n^{th} order polynomial, $P_n(x)$, which passes through $(n+1)$ given points, this is the equivalent of solving for the coefficients, a_i , of the expression

$$P_n(x) = \sum_{i=0}^n a_i x^i \quad (24)$$

This gives rise to the system of equations

$$\begin{array}{ccccccc} a_0 + a_1 x_1 + a_2 x_1^2 + \dots + a_n x_1^n & = & y_1 \\ a_0 + a_1 x_2 + a_2 x_2^2 + \dots + a_n x_2^n & = & y_2 \\ a_0 + a_1 x_3 + a_2 x_3^2 + \dots + a_n x_3^n & = & y_3 \\ \vdots & & \vdots \\ a_0 + a_1 x_{n+1} + a_2 x_{n+1}^2 + \dots + a_n x_{n+1}^n & = & y_{n+1} \end{array} \quad (25)$$

In terms of matrix algebra.

$$\begin{bmatrix} 1 & x_1 & x_1^2 & \dots & x_1^n \\ 1 & x_2 & x_2^2 & \dots & x_2^n \\ 1 & x_3 & x_3^2 & \dots & x_3^n \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n+1} & x_{n+1}^2 & \dots & x_{n+1}^n \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_{n+1} \end{bmatrix} \quad (26)$$

or in matrix notation.

$$X \vec{a} = \vec{y}. \quad (27)$$

The coefficient vector, \vec{a} , can then be solved for by inverting the square matrix and multiplying

$$\vec{a} = X^{-1} \vec{y}, \quad (28)$$

and these coefficients define equation (24). By theorem (5), this $P_n(x)$ is identical with that given by the previously developed interpolation formulas without the $R_n(x)$ term, i.e., equation (4).

Alternately, given that it is desired to find the n^{th} order polynomial, $P_n(x)$, which passes through m given points (where $m < n+1$) and which has given slopes for $(n+1 - m)$ points, from equation (24)

$$P_n(x) = \sum_{i=1}^n i a_i x^{i-1}. \quad (29)$$

Equations (24) and (29) give rise to the following system of equations.

$$\begin{aligned}
 a_0 + a_1 x_1 + a_2 x_1^2 + \dots + a_n x_1^n &= y_1 \\
 a_0 + a_1 x_2 + a_2 x_2^2 + \dots + a_n x_2^n &= y_2 \\
 \vdots &\vdots \\
 a_0 + a_1 x_m + a_2 x_m^2 + \dots + a_n x_m^n &= y_m \\
 0 + a_1 + 2a_2 x_{m+1} + \dots + na_n x_{m+1}^{n-1} &= y'_{m+1} \\
 \vdots &\vdots \\
 0 + a_1 + 2a_2 x_{n+1} + \dots + na_n x_{n+1}^{n-1} &= y'_{n+1}
 \end{aligned} \tag{30}$$

In terms of matrix algebra

$$\begin{bmatrix}
 1 & x_1 & x_1^2 & \dots & x_1^n \\
 1 & x_2 & x_2^2 & \dots & x_2^n \\
 \vdots & \vdots & \vdots & \ddots & \vdots \\
 1 & x_m & x_m^2 & \dots & x_m^n \\
 0 & 1 & 2x_{m+1} & \dots & nx_{m+1}^{n-1} \\
 \vdots & \vdots & \vdots & \ddots & \vdots \\
 0 & 1 & 2x_{n+1} & \dots & nx_{n+1}^{n-1}
 \end{bmatrix}
 \begin{bmatrix}
 a_0 \\
 a_1 \\
 a_2 \\
 \vdots \\
 a_n
 \end{bmatrix}
 =
 \begin{bmatrix}
 y_1 \\
 y_2 \\
 \vdots \\
 y_m \\
 y'_{m+1} \\
 \vdots \\
 y'_{n+1}
 \end{bmatrix} \tag{31}$$

or in matrix notation

$$\vec{X} \vec{a} = \vec{y} \tag{32}$$

The coefficient vector, \vec{a} , can then be solved for by inverting the square matrix and multiplying

$$\vec{a} = \vec{X}^{-1} \cdot \vec{y} . \quad (33)$$

Think of the given slopes as arising from a limiting process as one additional point is permitted to approach the given point associated with that slope. Then it is seen that the coefficients given by equation (33) are identical to those given by (28) and, therefore, define the unique interpolation polynomial $P_n(x)$ exacted by theorem (5).

The higher order derivatives can be similarly accommodated in the system of equations. However, the inclusion of first derivatives in the system of equations has special significance since these can be used to preserve curve smoothness at points representing transitions from one function formula to a different one.

This fact suggests that groups of given points can be partitioned for easier definitions of the interpolation forms with terminal slopes being used to preserve smoothness. This concept opens the door to other interpolation forms besides the polynomial expansions. Paragraph A.2.1 described the usefulness of irregular curves comprised of elliptical sections in drawing smooth curves. It is precisely the family of conics which provides the most promising forms with which to augment or supplant the polynomial interpolation formulas.

The general equation of second degree in x and y

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \quad (34)$$

has a locus a circle if $A = C$, $B = 0$;

an ellipse if $B^2 - 4AC < 0$;

a hyperbola if $B^2 - 4AC > 0$;

or a parabola if $B^2 - 4AC = 0$.

Equation (34) can be reexpressed as

$$y = a_0 + a_1x + a_2x^2 + a_3y^2 + a_4xy. \quad (35)$$

Given five consecutive points of a function, then the following system of equations obtains:

$$\begin{aligned}
 a_0 + a_1x_1 + a_2x_1^2 + a_3y_1^2 + a_4x_1y_1 &= y_1 \\
 a_0 + a_1x_2 + a_2x_2^2 + a_3y_2^2 + a_4x_2y_2 &= y_2 \\
 a_0 + a_1x_3 + a_2x_3^2 + a_3y_3^2 + a_4x_3y_3 &= y_3 \\
 a_0 + a_1x_4 + a_2x_4^2 + a_3y_4^2 + a_4x_4y_4 &= y_4 \\
 a_0 + a_1x_5 + a_2x_5^2 + a_3y_5^2 + a_4x_5y_5 &= y_5
 \end{aligned} \tag{36}$$

which can be expressed as

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 & x_1y_1 \\ 1 & x_2 & x_2^2 & y_2^2 & x_2y_2 \\ 1 & x_3 & x_3^2 & y_3^2 & x_3y_3 \\ 1 & x_4 & x_4^2 & y_4^2 & x_4y_4 \\ 1 & x_5 & x_5^2 & y_5^2 & x_5y_5 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} \tag{37}$$

We establish the following notation

$${}_5Z_0 \vec{a} = \vec{y} \tag{38}$$

where the numbers underneath the symbol for the square matrix mean that the system of equations arises from five given points and no specified derivatives at these points.

Solving for the coefficient vector

$$\vec{a} = {}_5Z_0^{-1} \vec{y}. \tag{39}$$

Equation (35), with the coefficients from equation (39), is the interpolation formula for the conic which passes through the five given points. If the three inner points lie above a cord connecting the two end points, then

$$y = \frac{1 - a_4x + \sqrt{(a_4^2 - 4a_2a_3)} x^2 - (2a_4 + 4a_1a_3) x + 1 - 4a_0a_3}{2a_3} \cdot (40)$$

If the three inner points lie below a cord connecting the two end points, then

$$y = \frac{1 - a_4x - \sqrt{(a_4^2 - 4a_2a_3)} x^2 - (2a_4 + 4a_1a_3) x + 1 - 4a_0a_3}{2a_3} \cdot (41)$$

Equations (40) and (41) assume that $a_3 \neq 0$. If $a_3 = 0$, then

$$y = \frac{a_0 + a_1x + a_2x^2}{1 - a_4x} \cdot (42)$$

Differentiating equation (35), implicitly and grouping obtains

$$y' = a_1 + 2a_2x + 2a_3yy' + a_4(xy' + y) \cdot (43)$$

Given four points of a function and the slope at one of these points, equations (35) and (43) can be used to yield the following system of equations.

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 & x_1y_1 \\ 1 & x_2 & x_2^2 & y_2^2 & x_2y_2 \\ 1 & x_3 & x_3^2 & y_3^2 & x_3y_3 \\ 1 & x_4 & x_4^2 & y_4^2 & x_4y_4 \\ 0 & 1 & 2x_1 & 2y_1y_1' & (x_1y_1' + y_1) \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_1' \end{bmatrix} \cdot (44)$$

Using the notation as for equation (38)

$${}^4Z_1 \vec{a} = \vec{y}, \quad (45)$$

and the notation indicates that this system of equations obtains from four given points and one specified slope. The coefficient vector is

$$\vec{a} = {}^4Z_1^{-1} \vec{y} \quad (46)$$

and equations (40), (41), or (42) give the $y(x)$ for interpolated points under the restrictions postulated for these equations.

With three points and two slopes given, the following system obtains:

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 & x_1 y_1' \\ 1 & x_2 & x_2^2 & y_2^2 & x_2 y_2' \\ 1 & x_3 & x_3^2 & y_3^2 & x_3 y_3' \\ 0 & 1 & 2x_1 & 2y_1 y_1' & (x_1 y_1' + y_1) \\ 0 & 1 & 2x_3 & 2y_3 y_3' & (x_3 y_3' + y_3) \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_1' \\ y_3' \end{bmatrix} \quad (47)$$

and

$$\vec{a} = {}^3Z_2^{-1} \vec{y}. \quad (48)$$

Again, equations (40), (41), or (42) give $y(x)$ for interpolated points.

The general formula, equation (35), can be truncated to get

$$y = a_0 + a_1 x + a_2 x^2 + a_3 y^2. \quad (49)$$

This is the formula for a conic section with lines of symmetry parallel to both the coordinate axes.

Given four points of a function, the following system of equations results using the form from equation (49).

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 \\ 1 & x_2 & x_2^2 & y_2^2 \\ 1 & x_3 & x_3^2 & y_3^2 \\ 1 & x_4 & x_4^2 & y_4^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} \quad (50)$$

The coefficient vector is

$$\vec{a} = {}_4Z_o^{-1} \vec{y}. \quad (51)$$

Equation (49) with the coefficients from equation (51) is the interpolation formula for the conic which passes through the four given points. If the two inner points lie above the cord connecting the two end points, then

$$y = \frac{1 + \sqrt{1 - 4a_3 (a_0 + a_1x + a_2x^2)}}{2a_3}, \quad a_3 \neq 0. \quad (52)$$

If the two inner points lie below a cord connecting the two end points, then

$$y = \frac{1 - \sqrt{1 - 4a_3 (a_0 + a_1x + a_2x^2)}}{2a_3}, \quad a_3 \neq 0. \quad (53)$$

If $a_3 = 0$, then

$$y = a_0 + a_1x + a_2x^2. \quad (54)$$

Differentiating equation (49), implicitly and grouping results in

$$y' = a_1 + 2a_2x + 2a_3y y' \quad (55)$$

Given three points and the slope at one of these points, equations (49) and (55) can be used to yield the following system of equations.

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 \\ 1 & x_2 & x_2^2 & y_2^2 \\ 1 & x_3 & x_3^2 & y_3^2 \\ 0 & -1 & 2x_1 & 2y_1y_1' \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_1' \end{bmatrix} \quad (56)$$

The coefficient vector is

$$\vec{a} = {}_3Z_1^{-1} \vec{y} \quad (57)$$

Equation (49) with the coefficient values from equation (57) gives the interpolation formula. If the inner point lies above a cord through the terminal points, then equation (52) applies. If the inner point lies below the cord, equation (53) applies. If $a_3 = 0$, equation (54) applies.

Given two points and their associated slopes, equations (49) and (55) can be used to yield the following system of equations.

$$\begin{bmatrix} 1 & x_1 & x_1^2 & y_1^2 \\ 1 & x_2 & x_2^2 & y_2^2 \\ 0 & 1 & 2x_1 & 2y_1y_1' \\ 0 & 1 & 2x_2 & 2y_2y_2' \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_1' \\ y_2' \end{bmatrix} \quad (58)$$

The coefficient vector is

$$\vec{a} = Z_2^{-1} \vec{y}. \quad (59)$$

Equation (49) with the coefficient values from equation (59) gives the interpolation formula. If

$$y_1' > \frac{y_2 - y_1}{x_2 - x_1} > y_2'$$

then equation (52) applies. If

$$y_1' < \frac{y_2 - y_1}{x_2 - x_1} < y_2'$$

then equation (53) applies. If $a_3 = 0$, then equation (54) applies.

The general formula, equation (35) can be further truncated to get

$$y = a_0 + a_1x + a_2x^2. \quad (60)$$

This is simply equation (24) for $n = 2$. Given three points, the coefficients can be obtained from equation (28) and these are inserted in equation (60) to get the interpolation formula:

Given two points and one slope, i.e., $m = 2$, the system of the form given by equation (30) and the coefficients obtained from equation (33) can be used. Again, these are inserted in equation (60) to interpolate.

If only two points and no slopes are given, the interpolation form reduces to the straight line.

$$y = a_0 + a_1x \quad (61)$$

where

$$\left. \begin{aligned} a_0 &= \frac{y_1 x_2 - y_2 x_1}{x_2 - x_1} \\ a_1 &= \frac{y_2 - y_1}{x_2 - x_1} \end{aligned} \right\} \quad (62)$$

Equation (35) can be truncated in other fashions. Perhaps one of the most popular truncated forms is to set $a_4 = 0$ and $a_3 = a_2$. Thus

$$y = a_0 + a_1 x + a_2 (x^2 + y^2). \quad (63)$$

This is the so called circular interpolation formula. Its popularity stems from its usefulness in automated machining techniques where much of the work can be laid out in terms of straight edges and "radiused" corners. However, these automated machining contours are not representative of the general interpolation problem and consequently, the circular interpolation formula may be found less flexible than equation (61). Certainly equation (63) is less adaptable than equations (35), (49) or (60) in accommodating more functional shapes in a manner conformable to the subjective application (to the given point set) of the axiomatic framework developed earlier.

In any application of conic interpolation, either proper testing must be performed to avoid anomolous representations of the function or procedural limits must be imposed to assure consistency with expected curve shapes.

A.4 CURVE FITTING

The previous text dealt with the problem of defining a function which passes through each and every one of a given set of points where the number of the constraints, either given points or slopes, was equal to the degrees of freedom of the substitute function. This section will treat the determination of a function when the number of points exceeds the number of degrees of freedom of the model relating the ordinates to the abscissas. This is done by relaxing the requirement that the curve pass through all points while requiring that the differences between the curve and the ordinates (called residuals), at any given abscissas, reflect a "best fit" according to a specified criterion. This may be expressed as

$$y_i = f(x_i) + e_i \quad (64)$$

where e_i is the residual at the i^{th} point.

With n points given, it is assumed that the function $f(x)$ depends on p , ($p \leq n$) - unknown constants called parameters - which will be denoted by $a_0, a_1, a_2, \dots, a_{p-1}$.

The relation at the i^{th} point is then given by

$$y_i = f(x_i, y_i : a_0, a_1, a_2, \dots, a_{p-1}) + e_i \quad (65)$$

Several methods can be employed to determine the unknown constants. One method called the "Method of Averages" is based on the assumption that the points can be grouped into sets such that for each set $\sum e_i = 0$. Summing the relations as given by equation (65) for a specific set of points

$$\sum y_i = \sum f(x_i, y_i : a_0, a_1, a_2, \dots, a_{p-1}) + 0. \quad (66)$$

Doing this for the p sets obtains p equations which can then be solved simultaneously for the p unknowns.

For example, suppose that it is desired to fit a conic to 10 given points:

$$(x_1, y_1), (x_2, y_2), \dots, (x_{10}, y_{10}).$$

Then equation (65) is of the form of equation (35) with the addition of the residual term

$$y_i = a_0 + a_1x_i + a_2x_i^2 + a_3y_i^2 + a_4x_iy_i + e_i. \quad (67)$$

Assuming that $e_1+e_2 = e_3+e_4 = e_5+e_6 = e_7+e_8 = e_9+e_{10} = 0$, the following system of equations obtains

$$\begin{bmatrix} 2 & (x_1+x_2) & (x_1^2+x_2^2) & (y_1^2+y_2^2) & -(x_1y_1+x_2y_2) \\ 2 & (x_3+x_4) & (x_3^2+x_4^2) & (y_3^2+y_4^2) & (x_3y_3+x_4y_4) \\ 2 & (x_5+x_6) & (x_5^2+x_6^2) & (y_5^2+y_6^2) & (x_5y_5+x_6y_6) \\ 2 & (x_7+x_8) & (x_7^2+x_8^2) & (y_7^2+y_8^2) & (x_7y_7+x_8y_8) \\ 2 & (x_9+x_{10}) & (x_9^2+x_{10}^2) & (y_9^2+y_{10}^2) & (x_9y_9+x_{10}y_{10}) \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} y_1+y_2 \\ y_3+y_4 \\ y_5+y_6 \\ y_7+y_8 \\ y_9+y_{10} \end{bmatrix} \quad (68)$$

which defines the unknown constants, a_j .

It can be seen that different ways of choosing the groups will lead to different values for the constants. Ordinarily, the groups are chosen so as to contain approximately the same number of residuals. If there are to be k residuals in each group, the first group contains the first k residuals, the second group contains the following k residuals, etc.

This method is expedient and useful for this reason, but it has the significant shortcoming that the null sum assumption may actually permit unreasonably large magnitudes of residuals. This possibility is aggravated by the reduced sample size brought on by the grouping of points.

In many fields of applied science, such as optics or microwave engineering, the degree to which the idealized figure is approached is measured in terms of the root mean square of deviation of actual shape to theoretical figure. This is a valid criterion to define best fit.

Of all curves approximating a given set of points, the curve having the property that $e_1^2 + e_2^2 + \dots + e_n^2$ is a minimum is called a best fitting curve.

A curve having this property is said to fit the given points in the least square sense and is called a least square curve. Thus if we set

$$E = \sum e_i^2, \quad (69)$$

the estimates for the unknown constants, a_j , will be determined from the condition

$$E = \min. \quad (70)$$

Substituting for the e_i in equation (69),

$$E = \sum_{i=1}^n \left[y_i - f(x_i, y_i : a_0, a_1, a_2, \dots, a_{p-1}) \right]^2. \quad (71)$$

It is observed that E is a convex second order function in the a_j and, therefore, its extremum is the minimum for this function. By setting the partial derivatives of E with respect to the a_j to zero, a system of equations is obtained which can be solved for the p a_j defining the least square curve.

Given n points, if it is required to least square-fit a conic of the form of equation (35), then equation (21) becomes

$$E = \sum_{i=1}^n \left[y_i - a_0 - a_1 x_i - a_2 x_i^2 - a_3 y_i^2 - a_4 x_i y_i \right]^2. \quad (72)$$

The five partial derivatives with respect to the a_j are given in Table A-1.

TABLE A-1

PARTIAL DERIVATIVES FOR SUM OF RESIDUAL SQUARES FOR A CONIC DEFINING EQUATION

$$\frac{\partial E}{\partial a_0} = -2 \sum y_i + 2na_0 + 2a_1 \sum x_i + 2a_2 \sum x_i^2 + 2a_3 \sum y_i^2 + 2a_4 \sum x_i y_i$$

$$\frac{\partial E}{\partial a_1} = -2 \sum x_i y_i + 2a_0 \sum x_i^2 + 2a_1 \sum x_i^2 + 2a_2 \sum x_i^3 + 2a_3 \sum x_i y_i^2 + 2a_4 \sum x_i^2 y_i$$

$$\frac{\partial E}{\partial a_2} = -2 \sum x_i^2 y_i + 2a_0 \sum x_i^2 + 2a_1 \sum x_i^3 + 2a_2 \sum x_i^4 + 2a_3 \sum x_i^2 y_i^2 + 2a_4 \sum x_i^3 y_i$$

$$\frac{\partial E}{\partial a_3} = -2 \sum y_i^3 + 2a_0 \sum y_i^2 + 2a_1 \sum x_i y_i^2 + 2a_2 \sum x_i^2 y_i^2 + 2a_3 \sum y_i^4 + 2a_4 \sum x_i y_i^3$$

$$\frac{\partial E}{\partial a_4} = -2 \sum x_i y_i^2 + 2a_0 \sum x_i y_i + 2a_1 \sum x_i^2 y_i + 2a_2 \sum x_i^3 y_i + 2a_3 \sum x_i y_i^3 + 2a_4 \sum x_i^2 y_i^2$$

In the a_j dimensions, E is a convex hypersurface and, because of the reasons given above, the single stationary point on this hypersurface is $E = \min$. At this stationary point

$$\frac{\partial E}{\partial a_j} = 0, j=0, 1, 2, \dots, (p-1). \quad (73)$$

If all the partials of Table A-1 are set equal to zero, the following system of equations in the a_j are obtained.

$$\begin{bmatrix} n & \Sigma x_i & \Sigma x_i^2 & \Sigma y_i^2 & \Sigma x_i y_i \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i y_i^2 & \Sigma x_i^2 y_i \\ \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i^4 & \Sigma x_i^2 y_i^2 & \Sigma x_i^3 y_i \\ \Sigma y_i^2 & \Sigma x_i y_i^2 & \Sigma x_i^2 y_i^2 & \Sigma y_i^4 & \Sigma x_i y_i^3 \\ \Sigma x_i y_i & \Sigma x_i^2 y_i & \Sigma x_i^3 y_i & \Sigma x_i y_i^3 & \Sigma x_i^2 y_i^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} \Sigma y_i \\ \Sigma x_i y_i \\ \Sigma x_i^2 y_i \\ \Sigma y_i^3 \\ \Sigma x_i y_i^2 \end{bmatrix} \quad (74)$$

This system is solved to determine the a_j for equation (35) which then yields the least square conic section for the given points. The equations represented by the matrix equation (74) are the normal equations for the least square conic.

Similarly, where equations (50), (61) and (62) are the defining equations, the following matrix equations respectively represent the normal equations for the least square conic with lines of symmetry parallel to coordinate axes, the normal equations for the least square parabola, and the normal equations for the least square line:

$$\begin{bmatrix} n & \Sigma x_i & \Sigma x_i^2 & \Sigma y_i^2 \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i y_i^2 \\ \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i^4 & \Sigma x_i^2 y_i^2 \\ \Sigma y_i^2 & \Sigma x_i y_i^2 & \Sigma x_i^2 y_i^2 & \Sigma y_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} \Sigma y_i \\ \Sigma x_i y_i \\ \Sigma x_i^2 y_i \\ \Sigma y_i^3 \end{bmatrix} \quad (75)$$

$$\begin{bmatrix} n & \Sigma x_i & \Sigma x_i^2 \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i^3 \\ \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \Sigma y_i \\ \Sigma x_i y_i \\ \Sigma x_i^2 y_i \end{bmatrix} \quad (76)$$

$$\begin{bmatrix} n & \Sigma x_i \\ \Sigma x_i & \Sigma x_i^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} = \begin{bmatrix} \Sigma y_i \\ \Sigma x_i y_i \end{bmatrix} \quad (77)$$

Equations (74) through (77) presume that all residuals are equally important. When it is desired to give more importance to some points relative to others, a method of assigning weights, w_i , to each point may be used where the summations comprising the elements of the matrices are modified to include the w_i as multipliers inside of the summation signs and n is replaced by Σw_i . To show just two examples of this weighting, equations (76) and (77) are modified to form equations (78) and (79), respectively.

$$\begin{bmatrix} \Sigma w_i & \Sigma w_i x_i & \Sigma w_i x_i^2 \\ \Sigma w_i x_i & \Sigma w_i x_i^2 & \Sigma w_i x_i^3 \\ \Sigma w_i x_i^2 & \Sigma w_i x_i^3 & \Sigma w_i x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \Sigma w_i y_i \\ \Sigma w_i x_i y_i \\ \Sigma w_i x_i^2 y_i \end{bmatrix} \quad (78)$$

$$\begin{bmatrix} \Sigma w_i & \Sigma w_i x_i \\ \Sigma w_i x_i & \Sigma w_i x_i^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} = \begin{bmatrix} \Sigma w_i y_i \\ \Sigma w_i x_i y_i \end{bmatrix} \quad (79)$$

Solution of equation (78) and (79) respectively gives the least square parabola and the least square line. This weighting scheme still affords p degrees of freedom and the extremum is still an unconstrained minima for the weighted sum of residuals squared.

If, however, it is desired that the fitted curve pass through a specific point, then the problem becomes a problem in constrained minima.

The methods of obtaining the minima first described can be used to solve the problem in constrained minima as follows: The constraining relation $\phi = [y_1 - f(x_1, y_1 : a_0, \dots, a_{p-1})] \neq 0$, can be solved for one of the unknowns, say a_0 , in terms of the remaining unknown coefficients, and the resulting expression is substituted for a_0 in $E(x_i, y_i : a_0, a_1, a_2, \dots, a_{p-1})$ to obtain $E(x_i, y_i : a_1, a_2, a_3, \dots, a_{p-1})$. The values of the a_j that yield a minima of E can be found by the methods just presented for unconstrained minima. But solution of ϕ for one of the a_j and substitution of this expression may be tedious and time consuming. An alternative approach is known as the "Method of Undetermined Coefficients" or as the "Method of Lagrange Multipliers." This method can best be presented by the following rule:

In order to determine the extreme values of a function

$$E(x, y : a_0, a_1, a_2, \dots, a_{p-1}) \quad (80)$$

whose unknown coefficients, a_j , are subject to m constraining relations

$$\phi_k(a_0, a_1, a_2, \dots, a_{p-1}) = 0, \quad k = 1, 2, \dots, m, \quad m < p. \quad (81)$$

form the function

$$F = E + \sum_{k=1}^m \lambda_k \phi_k \quad (82)$$

and determine the parameters λ_k and the values of $a_0, a_1, a_2, \dots, a_{p-1}$, from the p equations

$$\frac{\partial F}{\partial a_j} = 0, \quad j = 0, 1, 2, \dots, (p-1), \quad (83)$$

and the m equation (81).

Suppose that it is desired to least squares fit a straight line to n points subject to the constraint that the line must pass through the point (x_1, y_1) .

Here

$$\phi_1 = (y_1 - a_0 - a_1 x_1) = 0 \quad (84)$$

and

$$E = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2 \quad (85)$$

Then equation (82) becomes

$$F = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2 + \lambda_1 (y_1 - a_0 - a_1 x_1)$$

The partial derivatives of interest are

$$\frac{\partial F}{\partial a_0} = -2\sum y_i + 2na_0 + 2a_1 \sum x_i - \lambda_1 = 0$$

$$\frac{\partial F}{\partial a_1} = -2\sum x_i y_i + 2a_0 \sum x_i + 2a_1 \sum x_i^2 - \lambda_1 x_1 = 0 \quad (86)$$

$$\frac{\partial F}{\partial \lambda_1} = y_1 - a_0 - a_1 x_1 = 0.$$

Yielding the following system of equations

$$\begin{bmatrix} 2n & 2\sum x_i & -1 \\ 2\sum x_i & 2\sum x_i^2 & -x_1 \\ 1 & x_1 & 0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \lambda_1 \end{bmatrix} = \begin{bmatrix} 2\sum y_i \\ 2\sum x_i y_i \\ y_1 \end{bmatrix} \quad (87)$$

This is solved for the a_j for equation (62), giving a least square line constrained to pass through the point (x_1, y_1) .

Similarly, if the straight line is constrained to go through two points, (x_1, y_1) , and (x_2, y_2) , then we have

$$\begin{bmatrix} 2n & 2\sum x_i & -1 & -1 \\ 2\sum x_i & 2\sum x_i^2 & -x_1 & -x_2 \\ 1 & x_1 & 0 & 0 \\ 1 & x_2 & 0 & 0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \lambda_1 \\ \lambda_2 \end{bmatrix} = \begin{bmatrix} 2\sum y_i \\ 2\sum x_i y_i \\ y_1 \\ y_2 \end{bmatrix} \quad (88)$$

This obtains the same coefficient values, a_j , as the following equivalent system of equations

$$\begin{bmatrix} 1 & x_1 \\ 1 & x_2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \quad (89)$$

When the number of constraints equals the number of unknown coefficients in the deriving equation, the solution for extremal points obtains trivial results.

When the number of points, n , is large (hundreds), another method of smoothing can be accomplished by successively determining a least square parabola to a series of a given number of points. The value of the parabola for a point midway between the end abscissas is the value of the smoothed data. The series is advanced by dropping the earliest point and picking up the succeeding point outside of the last series, and the corresponding midpoint is computed. This operation is continued until a sequence of smooth data points is obtained. In one application where the data were electrocardiograph samples, a nine-point least square parabola yielded sufficiently smooth data and degraded the signal amplitude by less than 10 percent of the desired resolution.

A first order least square fit in this manner does not offer any particular advantages. A zero order least square fit according to this scheme is simply the method of moving averages where the first k ordinates are averaged and that value assigned as the ordinate for the $\left(\frac{k}{2} + 1\right)^{\text{th}}$ abscissa for even k or the $\left(\frac{k+1}{2}\right)^{\text{th}}$ abscissa for odd k.

A.5. BIBLIOGRAPHY

1. Abramowitz, Milton and Stegun, Irene A., *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, U.S. Government Printing Office, Washington, D.C.; 1964.
2. Allen, William H., *Dictionary of Technical Terms for Aerospace Use*, NASA SR7, National Aeronautics and Space Administration, Washington, D.C., 1965.
3. Alvarez, J. Carlos, I.O.C. To: File, 2-701,1A-69-81, "Coefficient Closed Forms for a Parabola Constrained by Three Points, or Two Points and One Slope," Philco-Ford Corporation, Houston, Texas, September 22, 1969.
4. Alvarez, J. Carlos, I.O.C To: Hines, 2-701-1A-69-82, "A Method for Incremental Stepping Along a Parabola," Philco-Ford Corporation, Houston, Texas, September 23, 1969.
5. Beers, Yardley, *Introduction to the Theory of Error*, Addison-Wesley Publishing Company, Inc., Palo Alto, California, 1953.
6. Caceres, Cesar A., et al, *Computers Electrocardiography and Public Health - A report of Recent Studies*, Control Data Corporation, Minneapolis, Minnesota, 1966.
7. Feller, William, *An Introduction to Probability Theory and Its Applications*, John Wiley and Sons, Inc., New York, 1950.
8. Ford, Lester R., *Differential Equations*, McGraw-Hill Book Company, Inc., New York, 1955.
9. Freiberger, W. F., Ed., *The International Dictionary of Applied Mathematics*, D Van Nostrand Company, Inc., Princeton, New Jersey, 1960.
10. French, Thomas E., and Vierck, Charles J., *A Manual of Engineering Drawing for Students and Draftsmen*, McGraw-Hill Book Company, Inc., New York, 1960.
11. French, Thomas E., and Vierck, Charles J., *Fundamentals of Engineering Drawing*, McGraw-Hill Book Company, Inc., New York, 1960.

12. Fuller, Gordon, *Analytic Geometry*, Addison-Wesley Publishing Company, Inc., Cambridge, Massachusetts, 1954.
13. Giesecke, Frederick E., *Technical Drawing*, The Macmillan Company, New York, 1958.
14. Hoelscher, Randolph P., *Basic Drawing for Engineering Technology*, John Wiley and Sons, Inc., New York, 1964.
15. Hogg, Robert V. and Craig, Allen T., *Introduction to Mathematical Statistics*, The Macmillan Company, New York, 1965.
16. James, Robert C., *University Mathematics*, Wadsworth Publishing Company, Inc., Belmont, California, 1963.
17. Kaplan, Wilfred, *Advanced Calculus*, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1952.
18. Kline, Morris, *Mathematics and the Physical World*, Doubleday and Company, Inc., Garden City, New York, 1959.
19. Knuth, Donald E., *The Art of Computer Programming*, Addison-Wesley Publishing Company, Menlo Park, California, 1968.
20. Kuo, Shan S., *Numerical Methods and Computers*, Addison-Wesley Publishing Company, Palo Alto, California, 1965.
21. Machol, Robert E., *System Engineering Handbook*, McGraw-Hill Book Company, Inc., New York, 1965.
22. Miller, Irwin, and Freund, John E., *Probability and Statistics for Engineers*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.
23. Rektorys, Karel, *Survey of Applicable Mathematics*, The M.I.T. Press, Cambridge, Massachusetts, 1969.
24. Smirnov, V. I., *A Course of Higher Mathematics*, Addison-Wesley Publishing Company, Inc., Palo Alto, California, 1964.
25. Sokolinkoff, I. S. and Redheffer, R. M., *Mathematics of Physics and Modern Engineering*, McGraw-Hill Book Company, Inc., New York, 1958.

26. Sokolinkoff, I. S. and Sokolinkov, E. S., *Higher Mathematics for Engineers and Physicists*, McGraw-Hill Book Company, Inc., New York, 1941.
27. Spiegel, Murray R., *Schaum's Outline of Theory and Problems of Statistics*, Shawn Publishing Company, New York, 1961.
28. Uspensky, J. V., *Theory of Equations*, McGraw-Hill Book Company, Inc., New York, 1948.
29. Wilkes, M. V., *A Short Introduction to Numerical Analysis*, Cambridge University Press, London, 1966.
30. Zozzara, Frank, *Engineering Drawing*, McGraw-Hill Book Company, Inc., New York, 1958.

APPENDIX B

NEAREST CHARACTER BOX COORDINATES

The following Table B-1 and following formula may be used to calculate the nearest character box coordinate to a given 1024 x 1024 coordinate input.

TABLE B-1

CHARACTER SIZE CONSTANT TABLE

Size	K_o		K_s	
	X	Y	X	Y
1	6	23	12	24
2	6	22	16	32
3	22	27	18	36
4	24	31	24	48
5	15	24	30	60

FORMULA: $\frac{IN - K_o}{K_s} = Q \text{ and } R$

If $R \leq \frac{K_s}{2}$, then $(K_s \cdot Q) + K_o = \text{CB coordinate}$;

If $R > \frac{K_s}{2}$, then $[K_s \cdot (Q + 1)] + K_o = \text{CB coordinate}$

where

K_o = coordinate of lower left character box (CB)

K_s = space between CB centers (character space)

Q = quotient

R = remainder

IN = input coordinate X or Y value.

NOTE: Substitute K_o value for IN when IN is less than K_o .

APPENDIX C

EXTERNAL INPUT FORMATS AND CODES

C.1 SYMBOLIC WORD FORMATS

<u>CARD COLUMNS</u>	<u>LEGAL ENTRY</u>
<u>Control Command Word</u>	
1-3	COM
4	D - Dynamic B - Background
11-12	Cluster 01-12
15-16	Channel 01-08
21-24	Load Address 0000 to 1023
<u>Background Request Command Word</u>	
1-4	BGRD
5-8	Background No.
11-12	Cluster 01-12
15-16	Channel 01-08
<u>VSM Command Word</u>	
1-4	VSMC
13-16	TV CHAN
<u>Unload Address Instruction Word</u>	
1-4	SUAD
5-8	Unload Address 0000-1023
<u>Begin Display Instruction Word</u>	
1-4	BFDP

CARD COLUMNS

LEGAL ENTRY

No Operation Instruction Word

1-4 NOOP

JUMP Instruction Word

1-4 Jump

5-8 Jump Address 0000 to 1023

Vector Data Word

1-4 VECT

17-20 X2 Coordinate

21-24 Y2 Coordinate

25-28 X1 Coordinate

29-32 Y1 Coordinate

Symbol Data Word

1-4 SYMS

10 Size 1-5

13-16 Symbol Card Image Code

17-20 X Coordinate Address

21-24 Y Coordinate Address

Typewriter Data Word

1-4 TYPE

13-16 1st Symbol*

21-24 2nd Symbol*

29-32 3rd Symbol*

37-40 4th Symbol*

45-48 5th Symbol*

*Card Image Code

C.2. DTE/DRAFT II SYMBOL LIBRARY CODES

<u>DTE DISK LOCATION</u>	<u>DISPLAY SYMBOL</u>	<u>OCTAL DTE 8-BIT CODE</u>	<u>CARD IMAGE CODE</u>
0	Spare	160	SP1
1	<u>1</u>	161	PERP
2	p	162	LRHO
3	i	163	II
4	j	164	JJ
5	k	165	KK
6	l	166	LL
7	-	167	-
8	°	140	DEG
9	∫	141	ANG
10	%	142	PCT
11	0	143	0
12	1	144	1
13	2	145	2
14	3	146	3
15	4	147	4
16)	050)
17	&	121	AND
18	Spare	122	SP2
19	α	123	LALP
20	A	124	A
21	B	125	B
22	C	126	C
23	D	127	D
24	Δ	070	DEL
25	σ	071	LSIG

<u>DTE DISK LOCATION</u>	<u>DISPLAY SYMBOL</u>	<u>OCTAL DTE 8-BIT CODE</u>	<u>CARD IMAGE CODE</u>
26	ϕ	072	LPHI
27	(a)	073	(a)
28	a	104	AA
29	b	105	BB
30	c	106	CC
31	d	107	DD
32	e	110	EE
33	f	111	FF
34	g	112	GG
35	h	113	HH
36	I	114	LBRC
37	β	065	LBTA
38	γ	066	LGAM
39	δ	067	LDEL
40	E	130	E
41	F	131	F
42	G	132	G
43	H	133	H
44	θ	134	LTHE
45	Spare	045	SP4
46	\sim	046	CYC
47	(047	(
48	5	150	5
49	6	151	6
50	7	152	7
51	8	153	8
52	9	154	9

<u>DTE DISK LOCATION</u>	<u>DISPLAY SYMBOL</u>	<u>OCTAL DTE 8-BIT CODE</u>	<u>CARD IMAGE CODE</u>
53	☐	025	DBOX
54]	026	RBRC
55	±	027	PM
56		170	VBAR
57	m	171	MM
58	n	172	NN
59	o	173	OO
60	p	174	PP
61	ε	175	LEPS
62	□	006	BOX
63	#	007	NUM
64	♦ Illegal on D/TV	210	CSTR
65	M	211	M
66	N	212	N
67	O	213	O
68	P	214	P
69	η	215	LETA
70	Σ	366	SIGM
71	Φ	367	PHI
72	v	230	VV
73	w	231	WW
74	x	232	XX
75	y	233	YY
76	z	234	ZZ
77	Γ	345	GAM
78	Spare	346	SP5
79	v	347	LNU

<u>DTE DISK LOCATION</u>	<u>DISPLAY SYMBOL</u>	<u>OCTAL DTE 8-BIT CODE</u>	<u>CARD IMAGE CODE</u>
80	V	250	V
81	W	251	W
82	X	252	X
83	Y	253	Y
84	Z	254	Z
85	Spare	325	SP6
86	Spare	326	SP7
87	?	327	QUS
88	Λ	270	LAM
89	ω	271	LOMG
90	Ω	272	OMEG
91	⊙	273	LFLG
92	^	304	PNT
93	=	305	=
94	:	306	COL
95	>	307	GT
96	<	310	LT
97	/	311	/
98	*	312	*
99	;	263	;
100	+	264	+
101	,	265	,
102	.	266	.
103	λ	267	LLAM
104	•	330	FWEG
105	ψ	241	LPSI
106	Ψ	242	PSI

<u>DTE \ DISK LOCATION</u>	<u>DISPLAY SYMBOL</u>	<u>OCTAL DTE 8-BIT CODE</u>	<u>CARD IMAGE CODE</u>
107	Q	243	Q
108	R	244	R
109	S	245	S
110	T	246	T
111	U	247	U
112	Spare	220	SP8
113	Spare	221	SP9
114	Spare	222	SP10
115	q	223	QQ
116	r	224	RR
117	s	225	SS
118	t	226	TT
119	u	227	UU
120	—	200	UND
121	π	201	LPI
122	μ	202	LMU
123	I	203	I
124	J	204	J
125	K	205	K
126	L	206	L
127	◇	207	OSTR
None	EOT	377	EOT
None	Blank	063 or 103	SPAC
None	Carriage Return	000	CR
None	Margin Return	217	MR

: APPENDIX D

CONSTRUCTION OF ELLIPSES (CIRCLES)

When it is necessary to construct an ellipse (or circle) by means of straight line segments, the following routine can be used to develop the line segment end points.

The coordinates of the j^{th} point on the ellipse are:

$$X_j = X_o + a_1 \cos \left[\frac{2\pi}{n} (j-1) \right]$$

$$Y_j = Y_o + a_2 \sin \left[\frac{2\pi}{n} (j-1) \right]$$

where

X_o = the abscissa of the geometric center of the ellipse

Y_o = the ordinate of the geometric center of the ellipse

n = the number of points defined for the ellipse

a_1 = the horizontal semi axis of the ellipse

a_2 = the vertical semi axis of the ellipse

X_j, Y_j = the array of points on the ellipse.

APPENDIX E
DRAFT KEYBOARD FUNCTION CODES

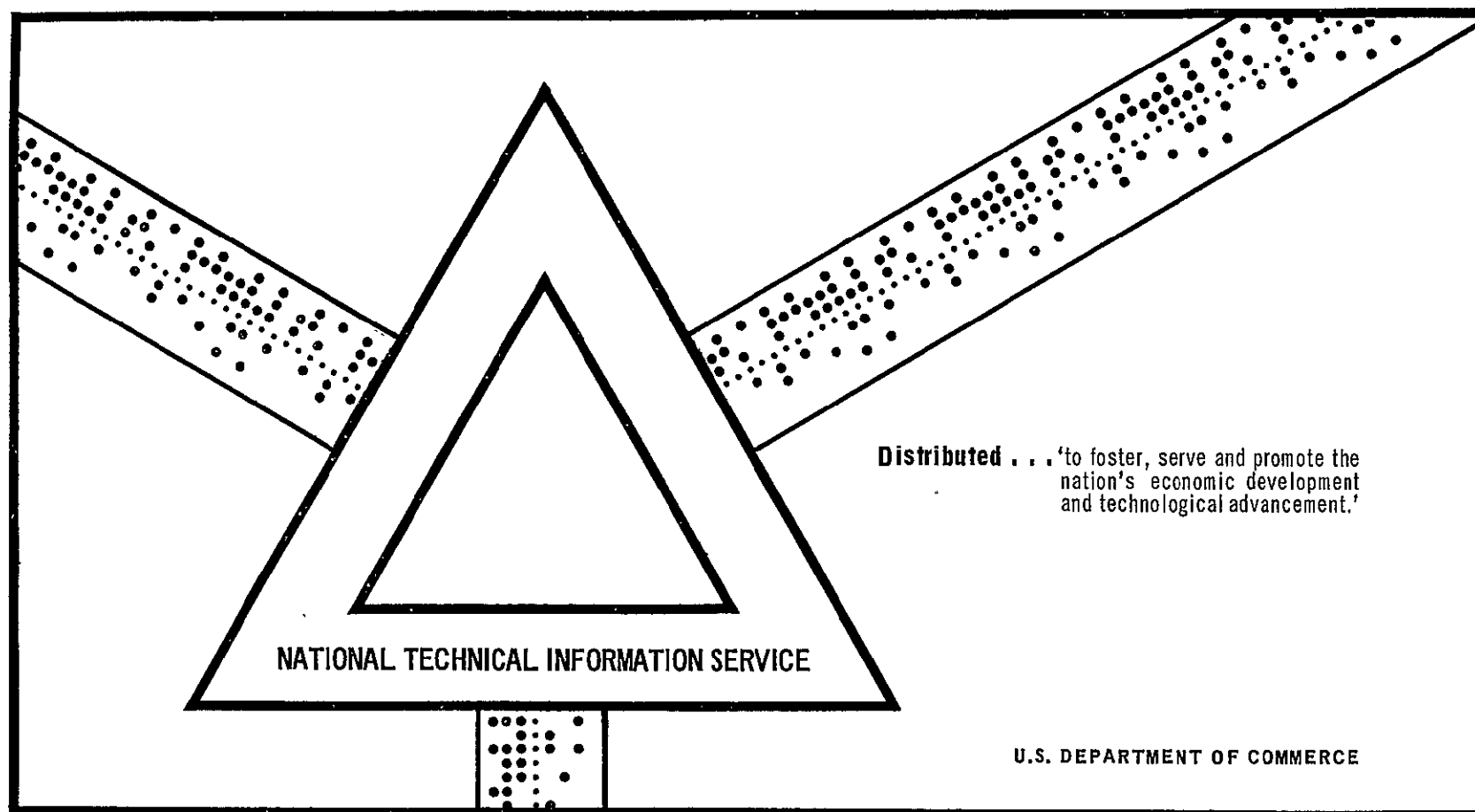
<u>FUNCTION</u>	<u>OCTAL 8-BIT CODE</u>
Grafacon Coordinates (Footswitch)	137
Left Monitor Action	157
Right Monitor Action	237
Character Size 1	016
Character Size 2	116
Character Size 3	216
Character Size 4	276
Character Size 5	356
Backspace (←)	136
Space	077
Line Up (↑)	056
Line Down (↓)	236
Superscript ($\frac{1}{2}$ ↑)	076
Subscript ($\frac{1}{2}$ ↓)	256
Character Space (CS)	156
Increment Space (INC)	176
Margin Return (MR)	217
Insert (INS)	336
Delete (DEL)	316
Tabulate (TAB)	117
Dynamic (DYN)	057
Tab Set	037
Tab Clear	017

<u>FUNCTION</u>	<u>OCTAL 8-BIT CODE</u>
Carriage Return	000
EOT	777
Blank	103
Spare Code	036
Spare Code	376

N71-11326

PROGRAM REQUIREMENTS FOR THE DRAFT II SYSTEMS

25 September 1970



This document has been approved for public release and sale.